DAVID W. TAYLOR NAVAL SHIP RESEARCH AND DEVELOPMENT CENTER

Bethesda, Md. 20084

SHIP RESPONSE TIME HISTORY PREDICTIONS FOR A CONVENTIONAL PRELIMINARY CSGN DESIGN

by

L. E. Motter

and

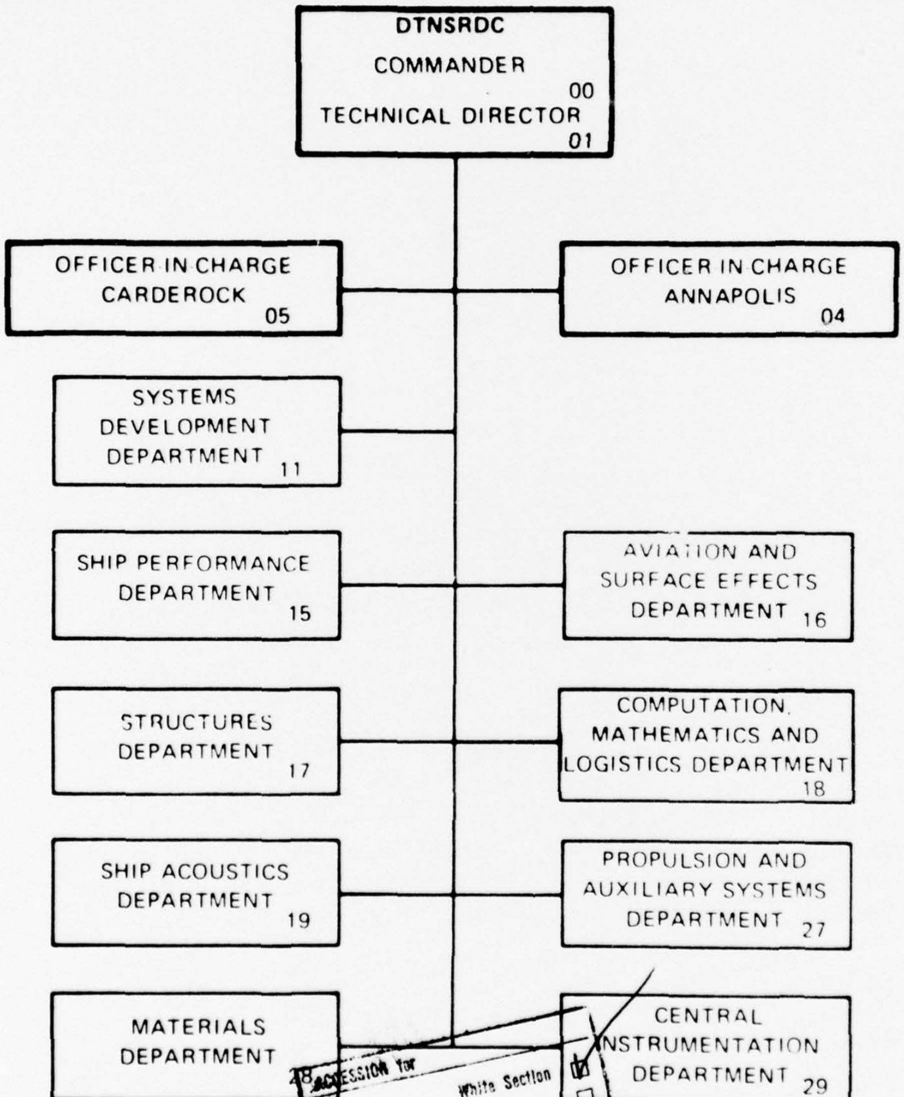
T. R. Applebee

SHIP PERFORMANCE DEPARTMENT

April 1977

SPD-724-07

MAJOR DTNSRDC ORGANIZATIONAL COMPONENTS



UNCLASSIFIED

SECURITY CLASSIFICATION OF THIS PAGE (When Data Entered)

REPORT DOCUMENTATION PAGE

READ INSTRUCTIONS BEFORE COMPLETING FORM

1. REPORT NUMBER: DTNSRDC SPD-724-07	2. GOVT ACCESSION NO.
3. RECIPIENT'S CATALOG NUMBER	
4. TITLE (and Subtitle): SHIP RESPONSE TIME HISTORY PREDICTIONS FOR A CONVENTIONAL PRELIMINARY CSGN DESIGN	5. TYPE OF REPORT & PERIOD COVERED
	6. PERFORMING ORG. REPORT NUMBER
7. AUTHOR(s): L. E. Motter and T. R. Applebee	8. CONTRACT OR GRANT NUMBER(s)
9. PERFORMING ORGANIZATION NAME AND ADDRESS: David W. Taylor Naval Ship R&D Center, Ship Performance Department, Bethesda, Maryland 20084	10. PROGRAM ELEMENT, PROJECT, TASK AREA & WORK UNIT NUMBERS: Work Unit Nos. 1-1568-863 & 1-1568-866
11. CONTROLLING OFFICE NAME AND ADDRESS: Naval Ship Engineering Center, Washington, D.C. 20362	12. REPORT DATE: April 1977
	13. NUMBER OF PAGES: 46
14. MONITORING AGENCY NAME & ADDRESS (if different from Controlling Office)	15. SECURITY CLASS. (of this report): Unclassified
	15a. DECLASSIFICATION DOWNGRADING SCHEDULE

16. DISTRIBUTION STATEMENT (of this Report)

APPROVED FOR PUBLIC RELEASE: DISTRIBUTION UNLIMITED

17. DISTRIBUTION STATEMENT (of the abstract entered in Block 20, if different from Report)

18. SUPPLEMENTARY NOTES

19. KEY WORDS (Continue on reverse side if necessary and identify by block number)

Ship Motion Prediction, Seaworthiness, CSGN, Time History Prediction

20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

The motion, velocity, and acceleration responses at ship center of gravity (CG) in long-crested seas were predicted for a preliminary conventional hull design of a new class of nuclear-powered, guided-missile strike cruiser. Time histories from the computer predictions are stored on computer permanent files for easy access and future use. Recently developed techniques for determining ship response time histories at various locations other than the ship CG and in short-crested seas were used to calculate sample

DD FORM 1 JAN 73 1473 EDITION OF 1 NOV 65 IS OBSOLETE

S/N 0102-LF-014-6601

1

UNCLASSIFIED

SECURITY CLASSIFICATION OF THIS PAGE (When Data Entered)

(14) (6) (10) (11) (12) 55p. 389694 1B

time histories of important ship responses.

A computer program was developed to read the predicted time histories and compute probabilities that specified motion response limits would be exceeded for various time periods.

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

ABSTRACT

The motion, velocity, and acceleration responses at ship center of gravity (CG) in long-crested seas were predicted for a preliminary conventional hull design of a new class of nuclear-powered, guided-missile strike cruiser. Time histories from the computer predictions are stored on computer permanent files for easy access and future use. Recently developed techniques for determining ship response time histories at various locations other than the ship CG and in short-crested seas were used to calculate sample time histories of important ship responses.

A computer program was developed to read the predicted time histories and compute probabilities that specified motion response limits would be exceeded for various time periods.

ADMINISTRATIVE INFORMATION

This work was funded by the Naval Ship Engineering Center under Work Requests WR 66038 and WR 66039 dated 24 May 1976 and WR 75239 dated 10 November 1976. The work is identified at the David W. Taylor Naval Ship Research and Development Center (DTNSRDC) as Work Units 1-1568-863 and 1-1568-866.

INTRODUCTION

As part of the process of designing a strike cruiser (CSGN) class, naval ordnance designers require estimates of the motion, velocity, and acceleration of the ship at positions where guns and radar control antennas will be located.

A rather complete prediction of significant ship motions, velocities, and acceleration was made for two preliminary designs of theCSGN in various sea conditions. However, the predictions necessary for ordnance performance evaluation require actual time histories of the ship responses at antenna and weapon locations from which statistics about the duration of extreme motion responses can be determined. Prediction techniques and computer programs do exist to predict ship response time histories at the ship center of gravity (CG). Programs are also available to predict response time histories for short-crested seas and to predict response time histories for any location on the ship from the time histories at the ship CG.

In the present investigation, a short supplemental program was written to analyze any given time history of response and to tabulate statistics about the amount of time the response exceeds a specified amplitude limit. These programs have been used to predict ship response time histories for the conventional CSGN hull, and samples of the results are shown. Copies of the programs used are included with the time histories on the computer disk packs which are on file.

DESCRIPTION OF HULL FORM

This hull configuration, C 17.2, is exactly the same as the conventional hull used in the previous CSGN seaworthiness prediction.[1] Table 1 shows the principal dimensions of the hull as calculated from the ship offsets and used by the computer. Figure 1 is a body plan of the ship as used by the computer. A preliminary set of bilge keels (not shown in the computer body plan) was included in the mathematical model of the ship.

The computer-determined dimensions and form coefficients agreed well with the design values. For example, the calculated displacement of 16,866 long tons (17,136 tonnes), not including bilge keels and skeg, was only about 1.8 percent less than the design displacement of 17,172 long tons (17,448 tonnes). Addition of the displacement of bilge keels and skegs would make the difference even less.

PREDICTION PROCEDURE

Ship responses were computed by using the CDC 6700 and the CDC 6600 computer systems available at the Center. All of the ship motion predictions are stored on two 844 removable disk packs titled CSGN01 and CSGN02.

[1] Motter, L.E. and T.R. Applebee, "Seaworthiness Predictions for Two Preliminary CSGN Designs," DTNSRDC Ship Performance Department Report SPD 724-01 (Sep 1976).

Many computer programs were used to predict the ship rigid body responses and statistical predictions presented in this report. Most of the major programs, as well as some of the smaller access programs, are documented and a reference for each is given herein as it is discussed. A program necessary to analyze the time history data is documented in the appendix. A copy of this analysis program is included on the disk pack, and instructions are given in the appendix for accessing the disk pack stored data and program.

PRESENT OPTIONS

Figure 2 is a flow chart of the present options for predicting time histories and the procedure for generating each type. The regular wave ship motion response amplitude operators (RAO's) referred to in the top of the chart were generated and stored on a disk pack by using the DTNSRDC Ship-Motion and Sea-Load Computer Program.[2] As shown in Figure 2, ship motion time histories in any specified long- or short-crested sea can be predicted at the ship CG or at any other location on the ship from the RAO's. The cosine squared spreading function, as recommended in Reference 3, is used to predict ship motion in short-crested seas. Any of these time histories can be generated by using a program called Time History Access Program which is documented in Reference 4.

Once any time history has been generated and stored on the disk pack, a time history analysis program (limit) is available to access it and tabulate the number of times a motion time history exceeds a preassigned motion amplitude limit (referred to as an *event*), to determine for how long the limit is exceeded for each event, and to estimate probabilities that the limit will be exceeded. A more detailed explanation of the program operation is given in

---

[2] Meyers, W.G. et al., "Manual - NSRDC Ship-Motion and Sea-Load Computer Program," NSRDC Report 3376 (Feb 1975).

[3] Baitis, A.E. et al., "Design Acceleration and Ship Motions for LNG Cargo Tanks," presented at 10th Naval Hydrodynamics Symposium, Mass. Inst. Tech. (Jun 1974).

[4] Baitis, A.E. et al., "A Non-Aviation Ship Motion Base for the DD 963, CG 26, FF 1052, FFG 7, and the FF 1040 Ship Classes," DTNSRDC Ship Performance Department Report SPD-738-01 (Dec 1976).

the appendix. Sample results of the time history analysis are presented later in this report.

TIME HISTORY PREDICTION

The ship motion, velocity, and acceleration RAO's presented in Reference 1 and stored on disk pack CSGN01 are used as input to the time history prediction program. Because of storage requirements involved, only time histories for those conditions listed in Table 2 were generated and stored on disk packs CSGN01 and CSGN02.

For each condition in Table 2, time histories for pitch, heave, roll, and vertical acceleration at the ship CG in long-crested seas were generated as examples of the normal time history prediction.

Bretschneider[5] irregular sea spectra of 1.0-ft significant wave height and modal wave periods of 9, 11, 13, and 15 sec were used in the prediction. Since ship responses are regarded as being linear with wave height in this work, the responses in seas with greater wave heights can be obtained by taking the results for unit significant wave height and multiplying by the desired significant wave height in feet.

The modal wave period is the period at which the maximum energy or peak of the wave energy spectrum occurs. The time history predictions cover a range of realistic modal periods, including some most likely to occur at sea as well as some that are less likely to occur but stimulate much more severe ship motion responses.

Considerably more information was generated by the computer than is reasonable or necessary to be shown in this report. Accordingly, only those conditions and ship responses of particular significance will be shown. These results will serve as examples of the available methods and possible applications of the prediction techniques.

Figure 3 shows an example of a roll and a heave acceleration time history as generated by the computer. These time histories are for a 30-knot ship

---

[5] Bretschneider, C.L., "Wave Generation by Wind, Deep and Shallow Water," in "Estuary and Coastline Hydrodynamics," edited by Arthur T. Ippen, McGraw-Hill, Inc., New York (1966) pp. 133-196.

speed at 75-deg heading in a long-crested sea with 16.9-ft (5.15 m) significant wave height and a spectra modal period of 9 sec. This condition causes one of the most severe responses for roll.

To illustrate use of the origin shift option in the Access Program, time histories were generated in long-crested seas for vertical displacement, velocity, and acceleration at the center of the roller path plane of the bow gun. This gun will be located on the ship longitudinal centerline 95.0 ft (28.96 m) aft of the forward perpendicular and 53.0 ft (16.15 m) above the ship baseline. Note that since roll and pitch are the same everywhere on the ship, roll and pitch time histories are the same at the gun as at the CG. Finally, roll and vertical accelerations at the CG in short-crested seas were generated as examples of the short-crested time history program. The headings, ship speeds, and modal periods of the sea spectrum used for each response are the conditions which give the most or nearly the most severe response in a sea with a 16.9-ft (5.15 m) significant height.

TIME HISTORY ANALYSIS

Time histories of ship responses have been predicted and analyzed for various ship location and sea condition to illustrate how the time history prediction and analysis programs can be used.

All sample calculations were made for a ship speed of 30 knots since motions were more severe than at the two lower speeds considered. All sample calculations considered the ship as operating in a Sea State 5 with a significant wave height of 16.9 ft (5.15 m). The modal period of the wave spectra is given with each example.

Table 3 enumerates the ship responses, headings, and spectral modal periods for which time histories were developed. In addition to presenting rms values for each response, the table presents four columns of numbers which appear in the form 0.7/393. The first number, or numerator of the fraction, is the amplitude limit used in the analysis of the ship response time history to determine the number of cycles which exceed the limit. The second number, or denominator of the fraction titled the number of events, is the number of cycles which exceed the specified amplitude limit in 30 min of ship operation.

The four limits were chosen in an effort to ensure that no less than about 10 percent nor more than about 80 percent of the cycles in a given time history would exceed any of the limits. Generally about 10 percent of the total number of cycles in a 30-min time history must exceed the limit in order to have a sufficient number of events to generate consistent statistical properties about time durations when limits will be exceeded. At the other extreme, it is assumed that the resulting duration time statistics will be out of the range of useful information when 80 to 90 percent of cycles exceed a given amplitude limit.

The probability of exceeding a ship response limit for each of the ship responses in Table 3 is shown in Figures 4a through 4i in the same order as listed in the table. The curves in the figures represent the probability distribution function as determined from analyzing a 30-min time history several times with a different limit for each analysis. The individual points, from each analysis of the time history, were so consistent that only the faired distribution function curve is shown in the figures.

It is known that the amplitudes of ship motion time histories are Rayleigh distributed and have a distribution function of

$$\text{Prob}\,\{r_a > R_L\} = e^{-\frac{R_L^2}{2\sigma^2}}$$

where R_L is the response limit amplitude and σ is the root mean square (rms). Using this formula and the frequency domain results in Reference 1, the probabilities of exceeding each of the four limits in Table 3 were computed and shown in Figures 4a through 4i with the time history analysis results. As seen in the figures, there was good agreement between the probabilities obtained from the time domain analysis and from the frequency domain results. This would be expected since the time histories were derived from the frequency domain results and is mentioned as evidence that the time history prediction from frequency domain results does work well. The figures indicate, for example, that if a gun cannot operate effectively when the roll is greater than $\pm$ 16 deg, then, as shown in Figure 4c, its operation will be interrupted by 30 percent of the waves encountered while operating at 30 knots in a 75-deg heading, and 16.9 ft (5.15 m) significant wave height.

The percentage of the total run time that the response exceeds any limit is shown in Figures 5a and 5i in the same order as listed in Table 3. The time was computed on the conservative side from the time history analysis by assuming that each event of the 0.5-sec, time-duration interval occurred for the upper time limit of the interval. These figures indicate, for example, that the roll angle will be greater than ± 16 deg for about 12.5 percent of the total run time even though about 30 percent of the roll cycles will exceed ± 16 deg while the ship is operating at 30 knots and a 75-deg heading with respect to the waves in a State 6 sea.

Figures 6a through 6i show the conditional probability density functions of the time durations given that the specified limit has been exceeded. These functions have been normalized so that the area in each bar of the graph represents the probability that, the limit having been exceeded, its duration is within the duration period of the time interval of the bar. Also, the total area of all the bars in each graph is 1.0, i.e., given that the response limit was exceeded, there is a 100-percent chance that it was exceeded for some length of time. As seen in the figures for all ship responses, as the response limit is increased, the most frequently occurring time duration is shorter.

As an example of the meaning of these curves, in Figure 6c the probability that the roll cycles will exceed ± 17 deg for a duration time between 1.5 and 2.0 sec is 48 percent per second times 0.5 sec, or 24 percent of the cycles.

Figures 7a through 7i show joint probability density functions of the time durations for four different amplitude limits. Again the density functions have been normalized so that the area in each bar of a graph represents the joint probability that (1) the limit is exceeded and (2) the period of the exceedance is within the duration time of the time interval of the bar. The total area in all the bars for any one response limit is the probability that the response limit is exceeded, as shown in Figure 4. For example, considering Figure 7c, the probability that a roll cycle will exceed ± 17 deg for a duration time of 1.5 to 2.0 sec is 12.5 percent per second times 0.5 sec or 6.3 percent.

To smooth out the bar graphs and to enable a comparison of the joint probability densities shown in Figures 7a through 7i, each bar graph in Figure 7 was hand faired to a smooth curve. An attempt was made to maintain the same area under the curve as in the correspondong bar graph. The resulting faired curves are presented in Figures 8a through 8i to show the relationship between the density functions for different response limits. As seen in these figures, the curves for different response limits vary in a regular fashion making it possible to estimate the time duration probabilities for response limits other than those used in the calculations.

RECOMMENDATIONS

The cost, time and computer storage required to predict and analyze time histories is considerable. If the mathematical form of the probability density function for the duration time could be developed, it may be possible to make predictions of the duration time interval directly from the rms results. Work has been done by Rice,[6] Price and Bishop[7] and by Tikhonov[8] with some success on simplified cases using numerical approximations. With the examples presented in this report as a guide, a reasonable method of predicting the duration time interval from the rms results may be possible, and should be attempted.

[6] Rice, S.O., "Mathematical Analysis of Random Noises," N. Wax, Ed. of Selected Papers on Noise and Stochastic Processes, Dover Publications, Inc. (1954).

[7] Price, W.G. and R.E.D. Bishop, "Probabilistic Theory of Ship Dynamics," Chapman and Hall (1974).

[8] Tikhonov, V.I., "The Distribution of the Duration of Excursions of Normal Fluctuations. Non-Linear Transformations of Stochastic Processes," Ed., Kusnetsov, Stratonovick and Tikhonov.

APPENDIX

PROGRAM LIMIT

The LIMIT program is used to analyze time histories that have been generated using the Time History Access Program (THACP), and to obtain various probabilities with relation to an imposed limit. The limit, which is an input variable is a boundary applied to the positive and negative sides of a time history. If a cycle exceeds the limit, the duration of time above the limit is noted. The predicted time histories are in a digital form with amplitude samples every 0.5 sec for the 30-min run. Therefore, time durations can be determined only to within $\pm$ 0.25 sec. For this reason the analysis of the time histories is set up in tabular form as shown in Table A.1. The number of occurrences of exceedance, referred to as "events," are ordered according to time duration periods (see example of output, as shown in the first two columns of Table A.1). From this information, the following statistical percentages are calculated and shown in the last three columns of Table A.1:

THE CONDITIONAL PROBABILITY OF DURATION TIME, defined as the probability that a particular duration time will occur if the limit is exceeded (the number of events/total number of events).

THE TOTAL TIME EXCEEDED, defined as that part of the entire run time that the limit is exceeded for a particular duration time (the number of events x time duration/total run time).

THE JOINT PROBABILITY, defined as the probability that for any cycle, the limit will be exceeded for a specific time duration (the number of events/total number of cycles).

INPUT

Data Card Set 1, one card, FORMAT (I5)

This card set contains one integer variable.

NRSP, Columns 1-5, is used to determine the number of responses to be analyzed (i.e., the number of cards to be read in Data Card Set 2).

Data Card Set 2, NRSP cards, FORMAT (I5,5X,F10.4)

This card set contains one integer and one floating point variable.

IRESP, Columns 1-5, is the response sequence number as defined in the output of the Time History Access Program.

LIM, Columns 11-20, is the boundary or limit, in appropriate units to be imposed on the time history.

(Note that Data Card Set 2 is repeated for each new response or limit to be analyzed.)

A sample of the entire computer card deck necessary to access the disk pack and run the program is shown in Figure A.1.

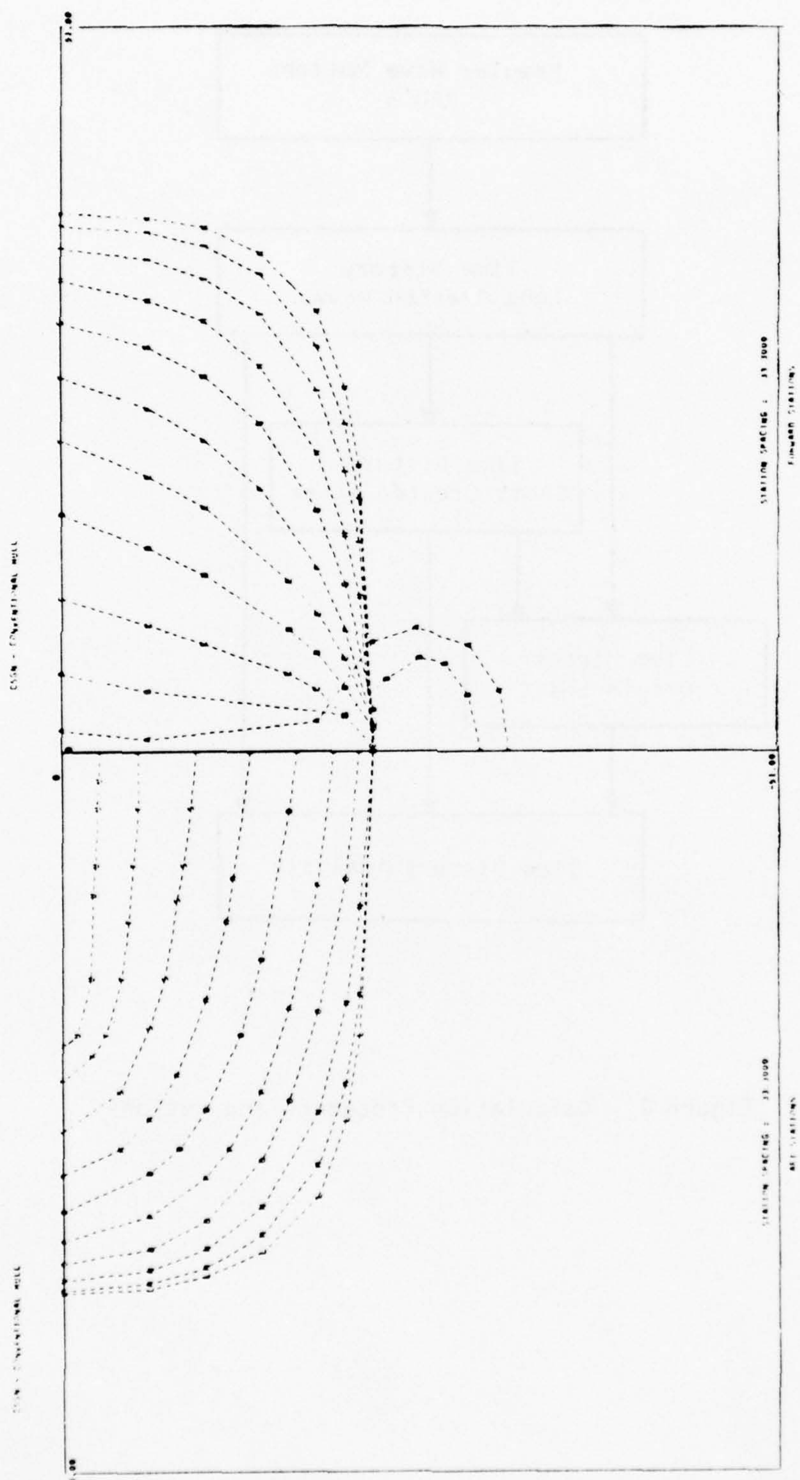


Figure 1 - Body Plan of CSGN Conventional Hull (C 17.2) Used in the Computer

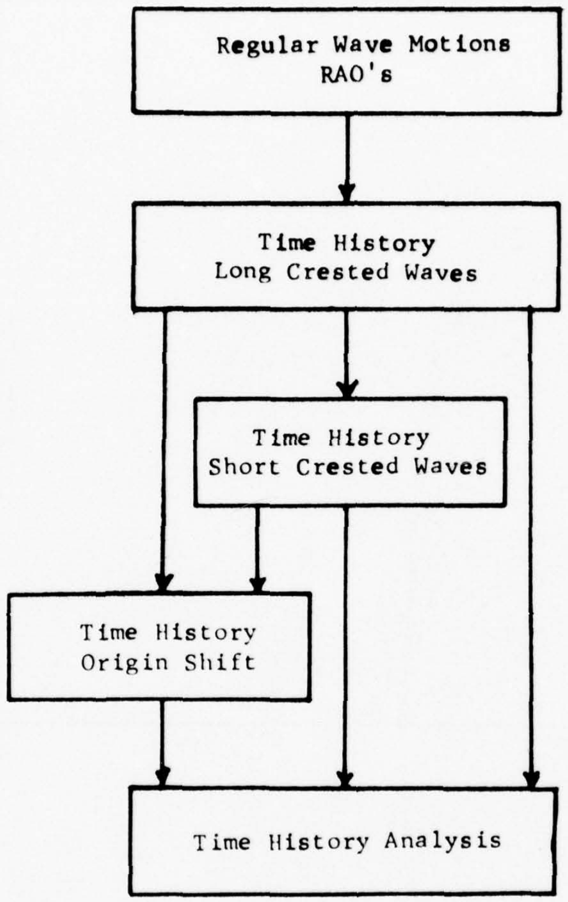
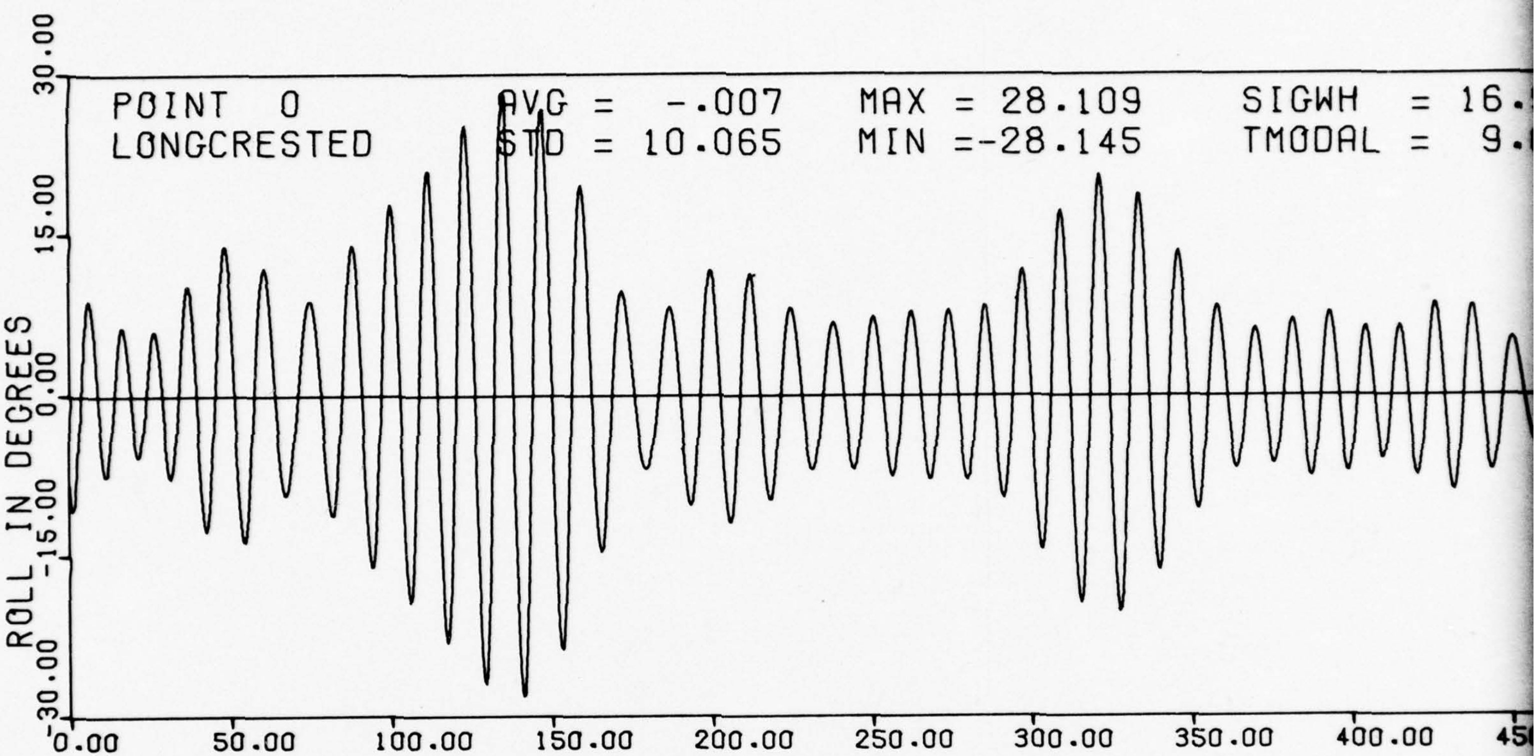
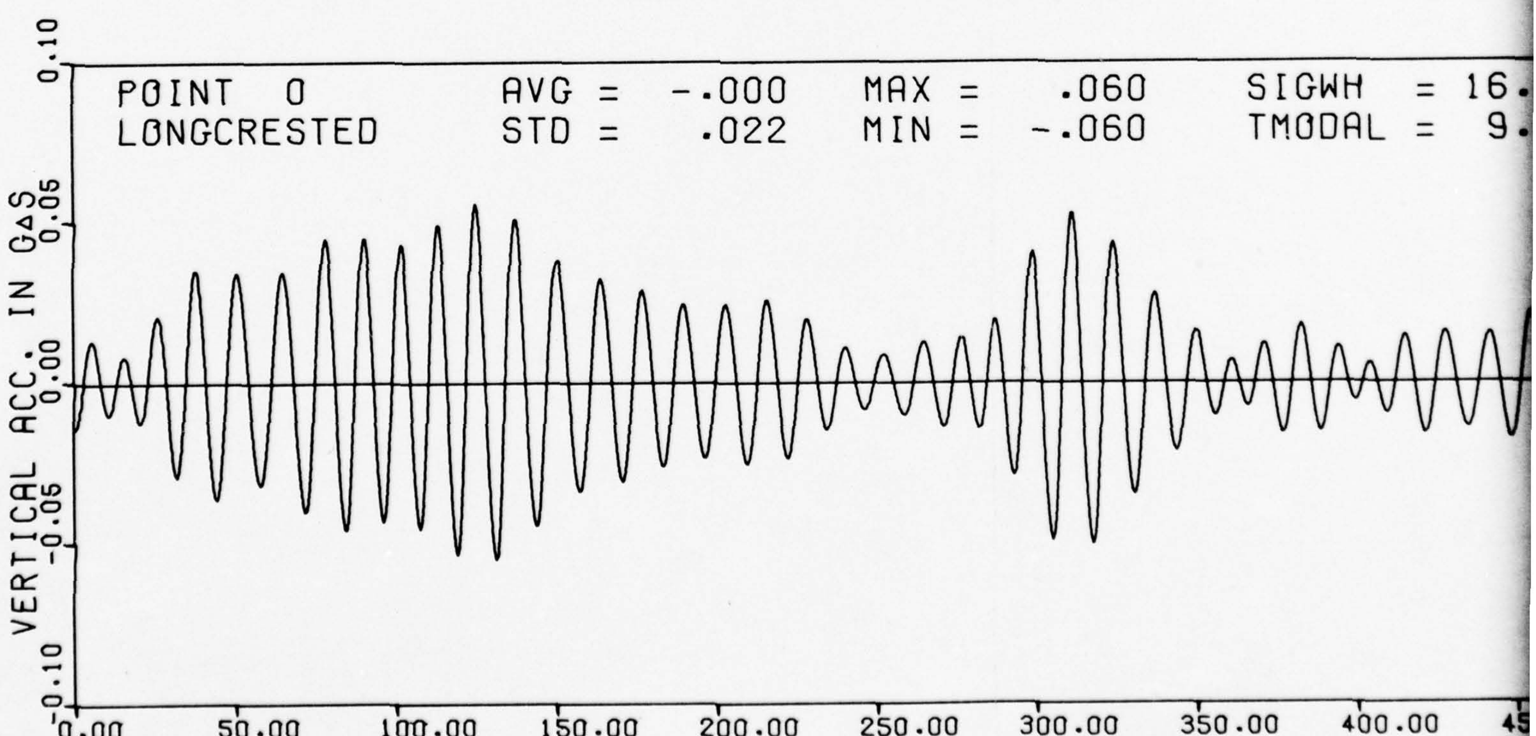


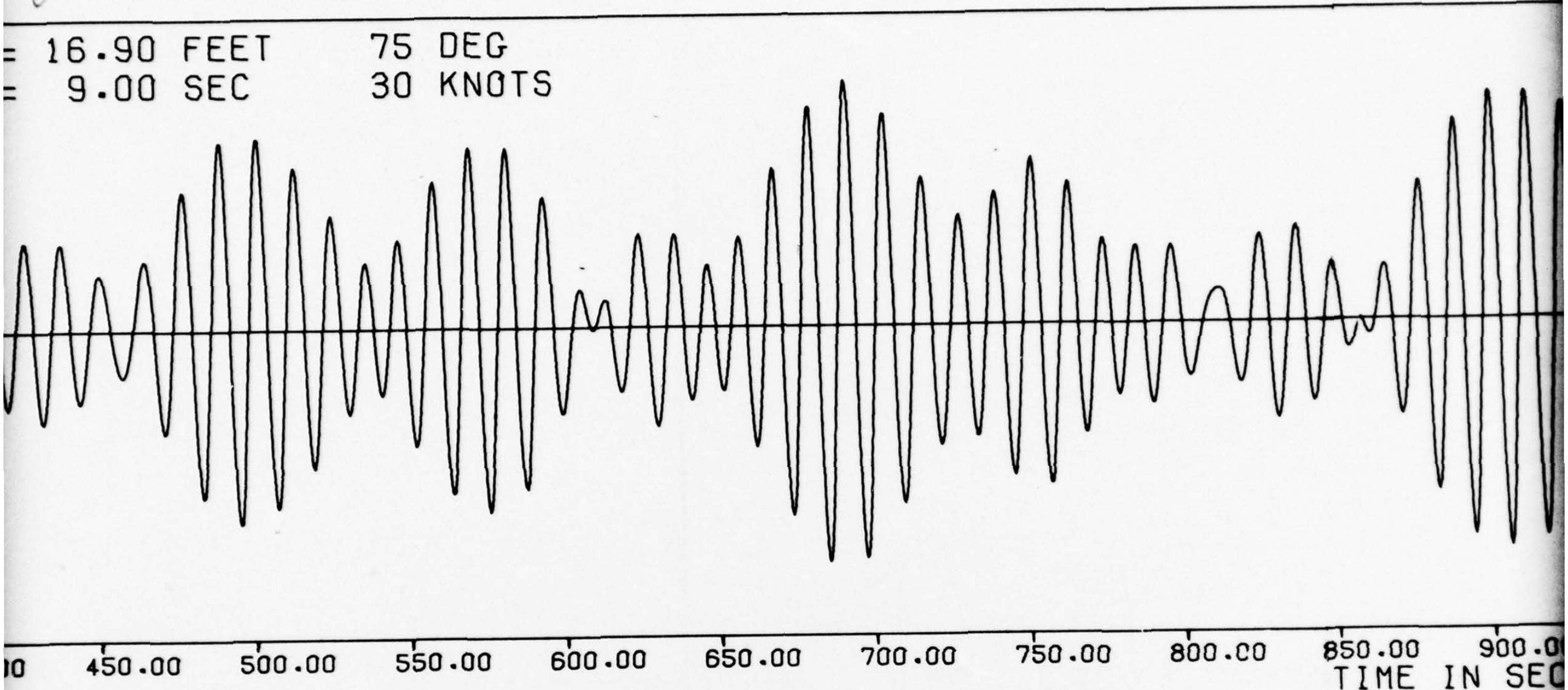
Figure 2 - Calculation Procedure and Options

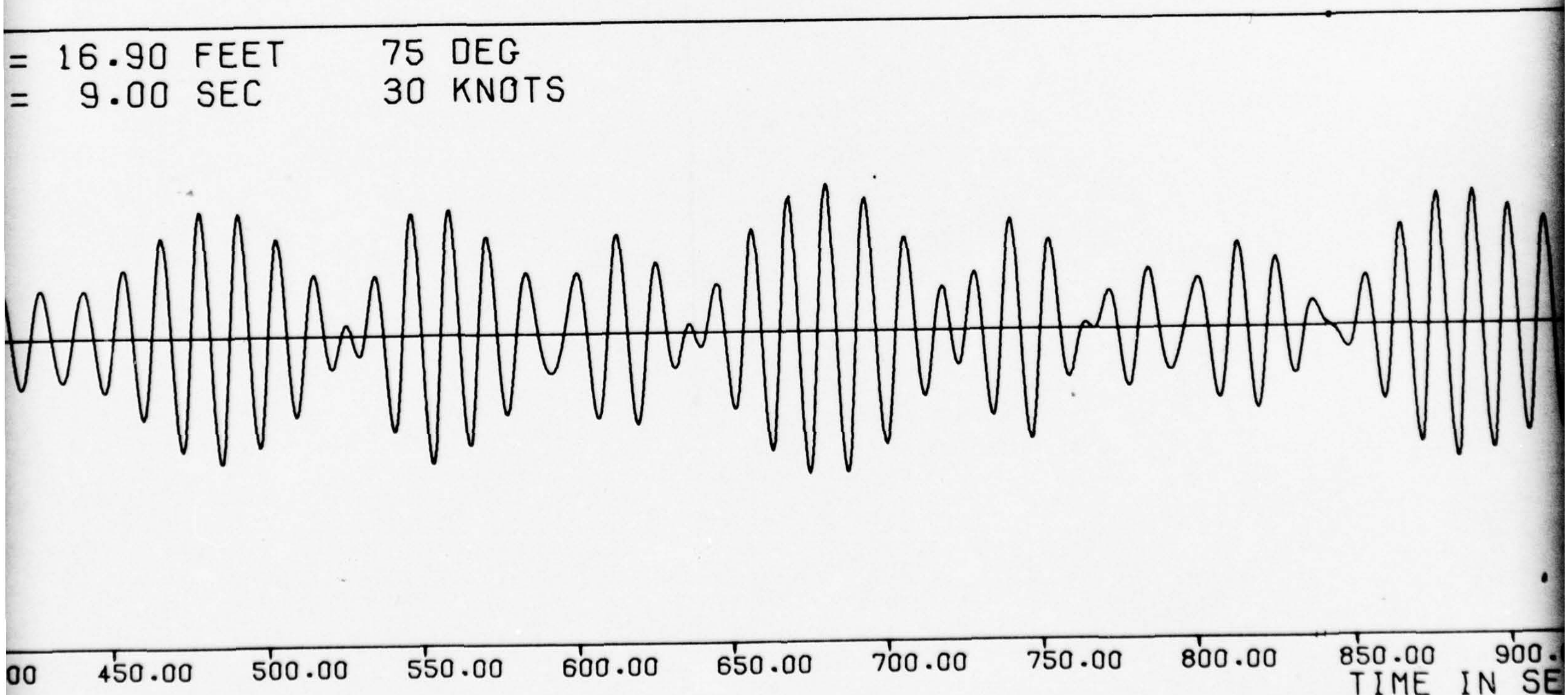

POINT 0
LONGCRESTED
AVG = -.007
STD = 10.065
MAX = 28.109
MIN =-28.145
SIGWH = 16.
TMODAL = 9.
ROLL IN DEGREES
30.00
15.00
0.00
-15.00
-30.00
0.00
50.00
100.00
150.00
200.00
250.00
300.00
350.00
400.00


POINT 0
LONGCRESTED
AVG = -.000
STD = .022
MAX = .060
MIN = -.060
SIGWH = 16.
TMODAL = 9.
VERTICAL ACC. IN G'S
0.10
0.05
0.00
-0.05
-0.10
0.00
50.00
100.00
150.00
200.00
250.00
300.00
350.00
400.00

2

CSGN - CONVENTIONAL HU
RESPONSE TIME HISTORIE





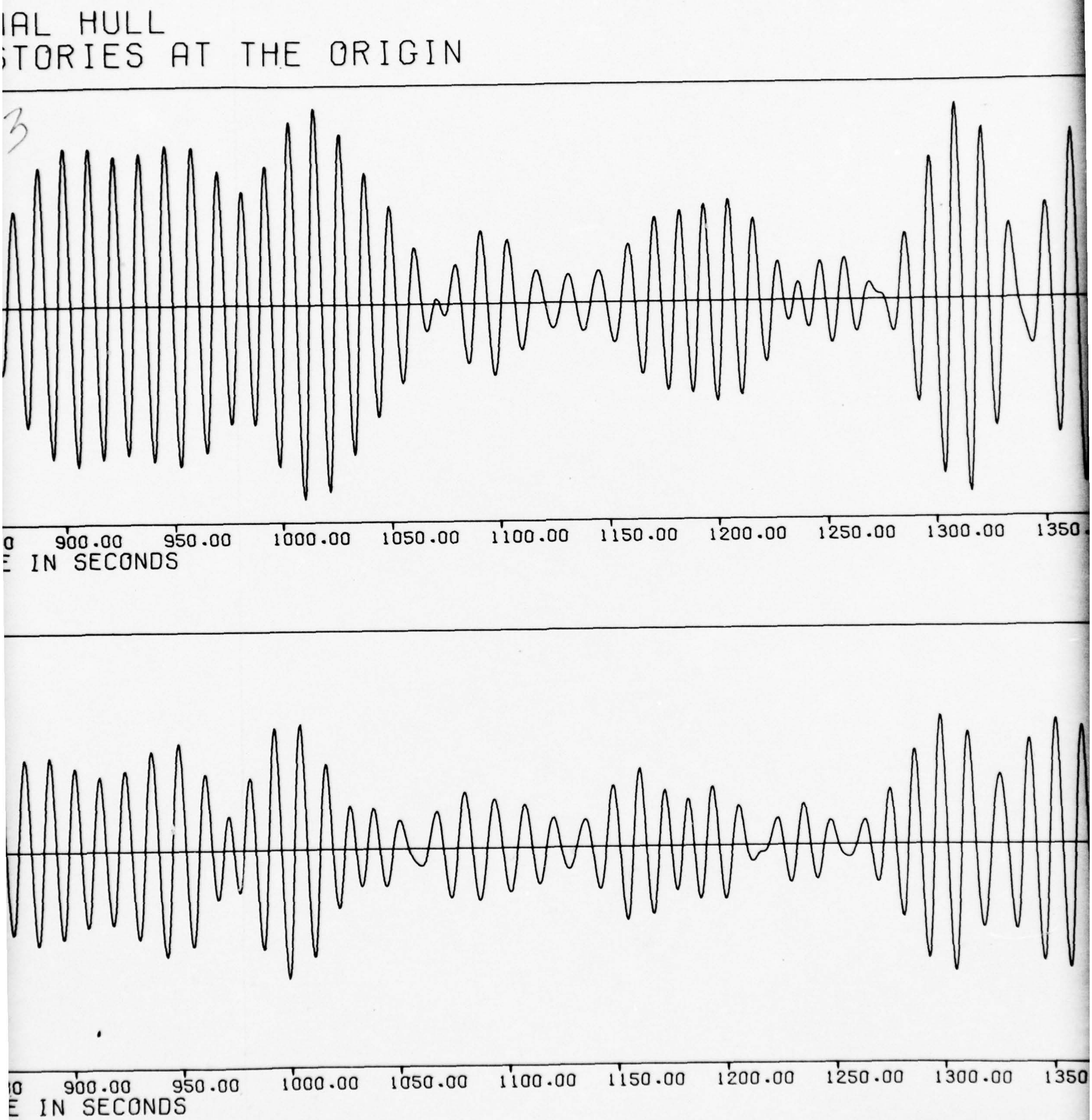
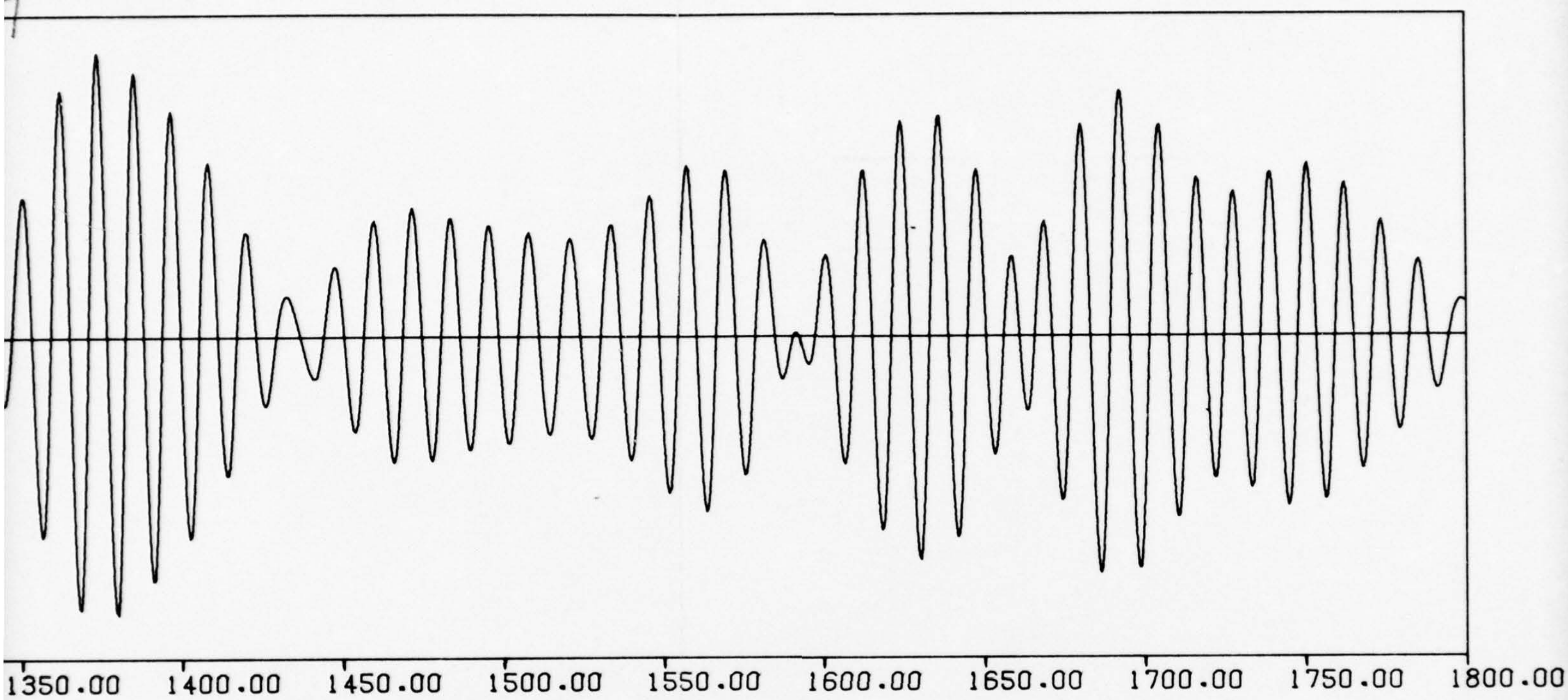
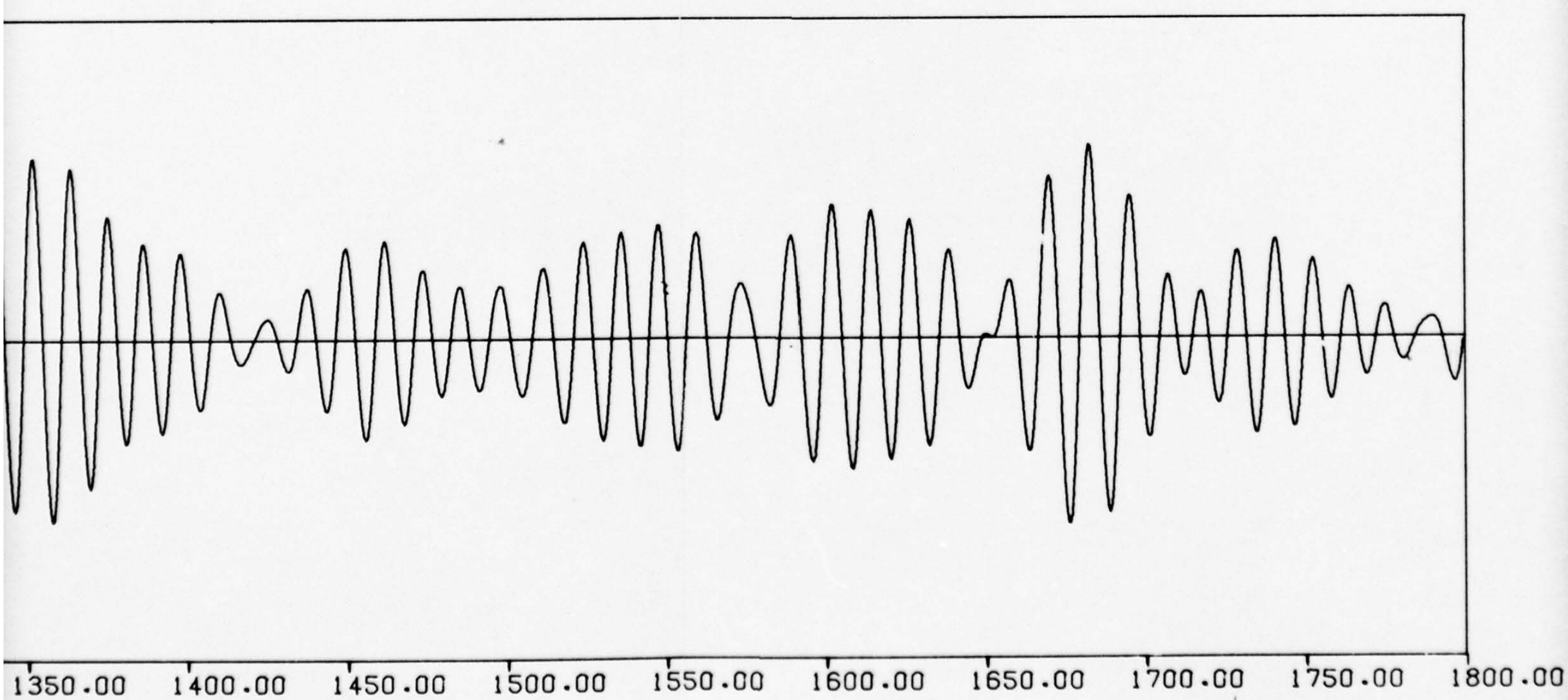


Figure 3 - Sample of Predic





redicted Time Histories

Figure 4 - Probability Distribution Functions of Ship Responses for 30-Knot Speed in Sea State 6 (16.9 ft (5.15 m) Significant Wave Height)

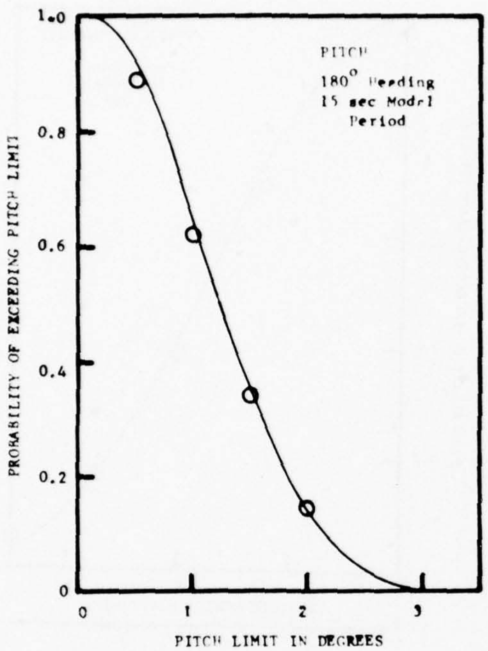


Figure 4a - Pitch in Long Crested Waves

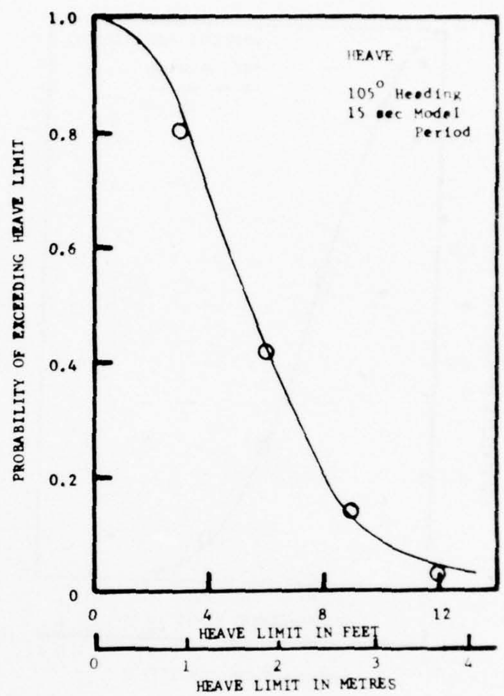


Figure 4b - Heave in Long Crested Waves

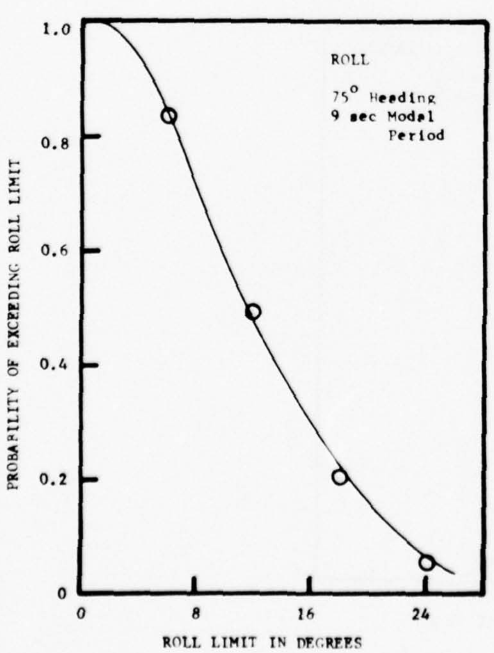


Figure 4c - Roll in Long Crested Waves

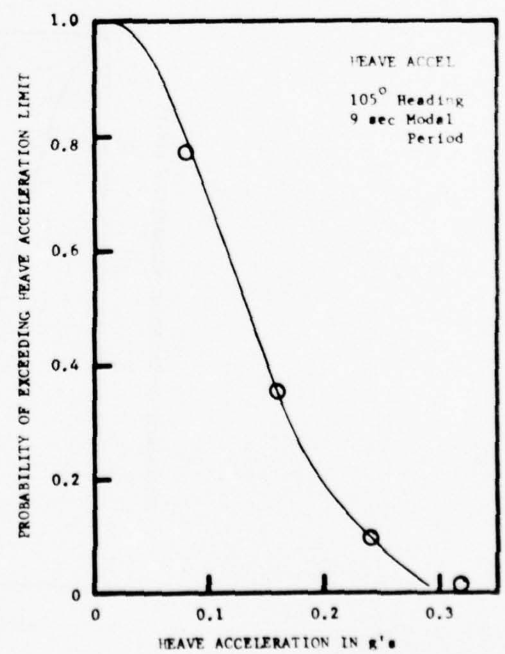


Figure 4d - Heave Acceleration in Long Crested Waves

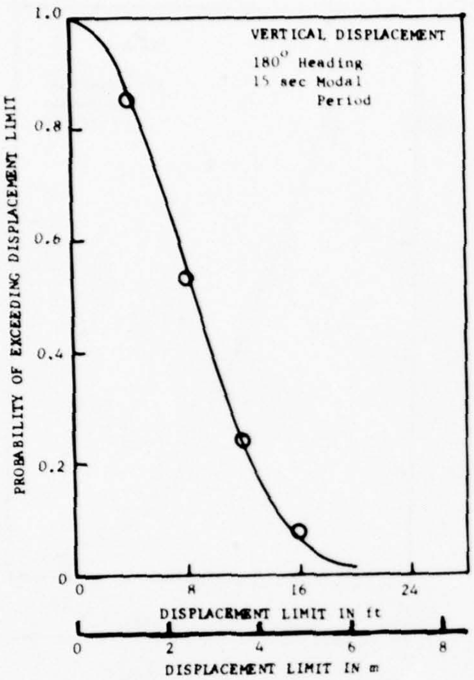


Figure 4e - Vertical Displacement at the Bow Gun in Long Crested Waves

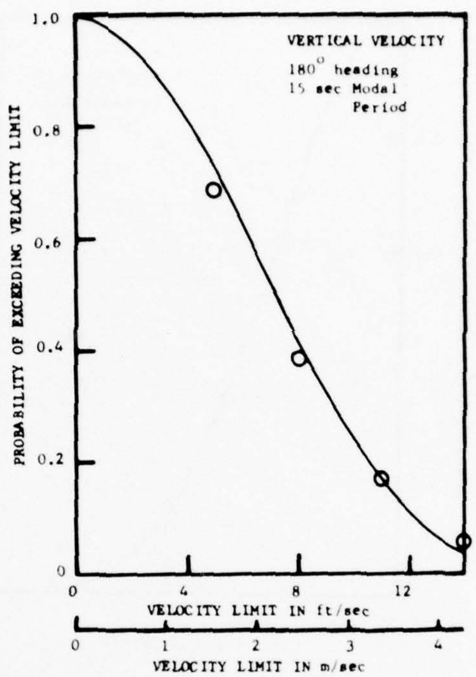


Figure 4f - Vertical Velocity at the Bow Gun in Long Crested Waves

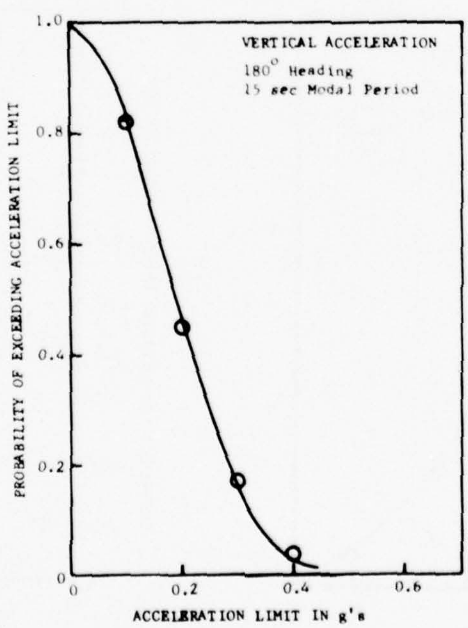


Figure 4g - Vertical Acceleration at the Bow Gun in Long Crested Waves

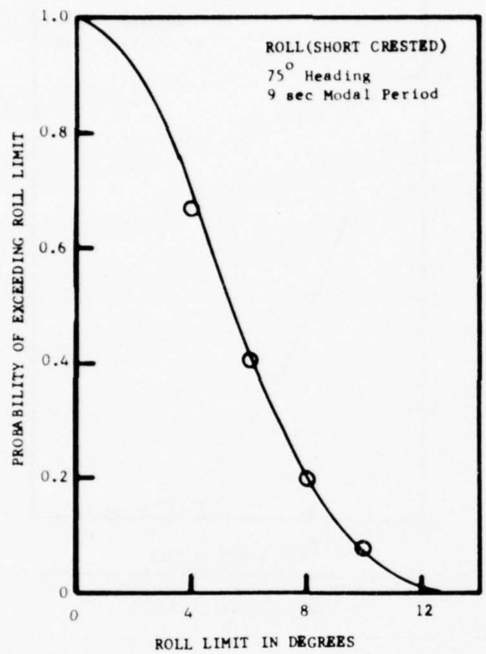


Figure 4h - Roll in Short Crested Waves

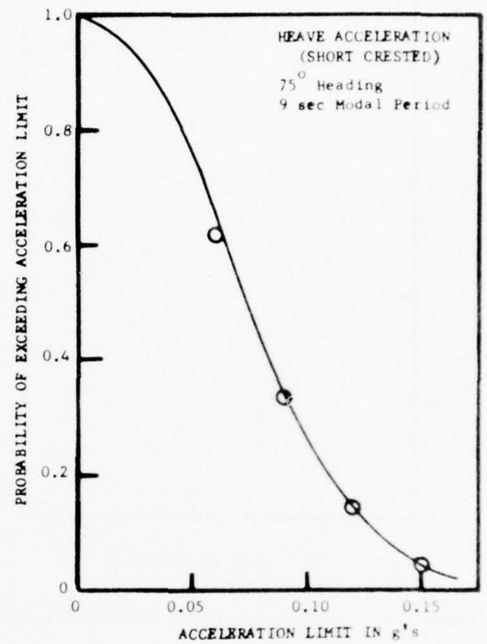


Figure 4i - Vertical Acceleration in Short Crested Waves

Figure 5 - Percentage of Time the Ship Response Limit is Exceeded for 30-Knot Speed in Sea State 6 (16.9 ft (5.15 m) Significant Wave Height)

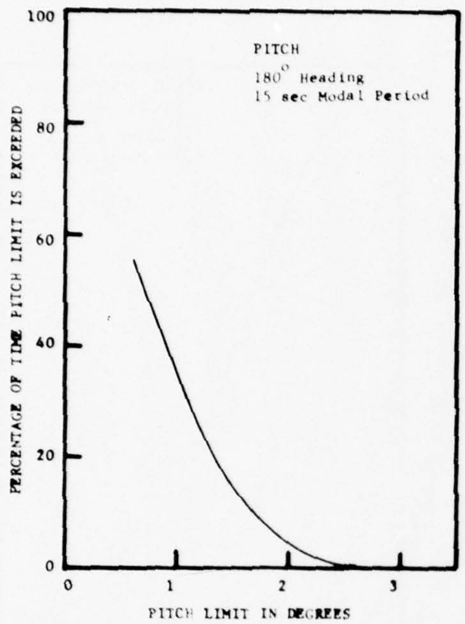


Figure 5a - Pitch in Long Crested Waves

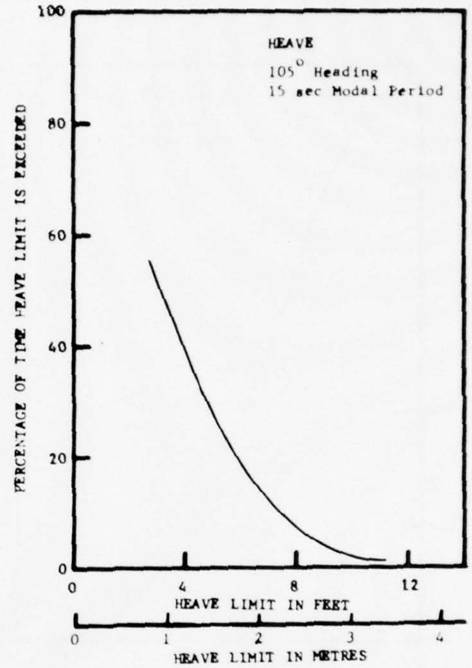


Figure 5b - Heave in Long Crested Waves

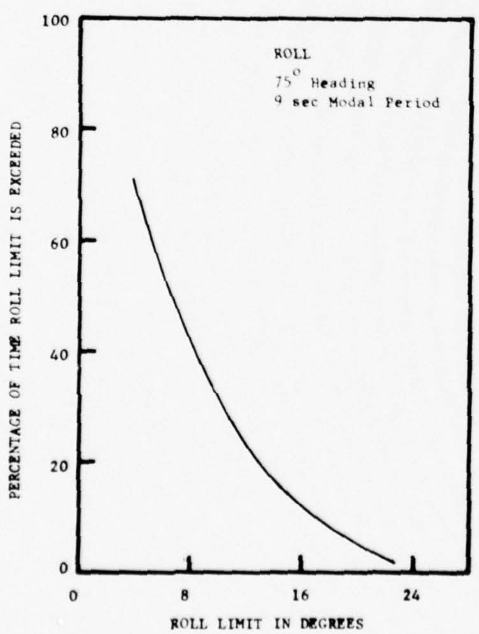


Figure 5c - Roll in Long Crested Waves

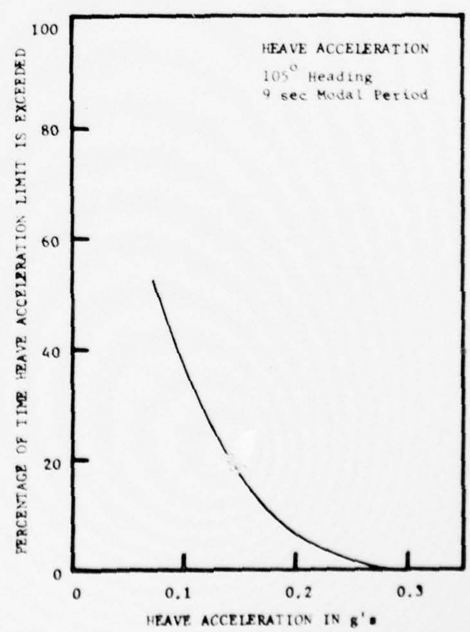


Figure 5d - Heave Acceleration in

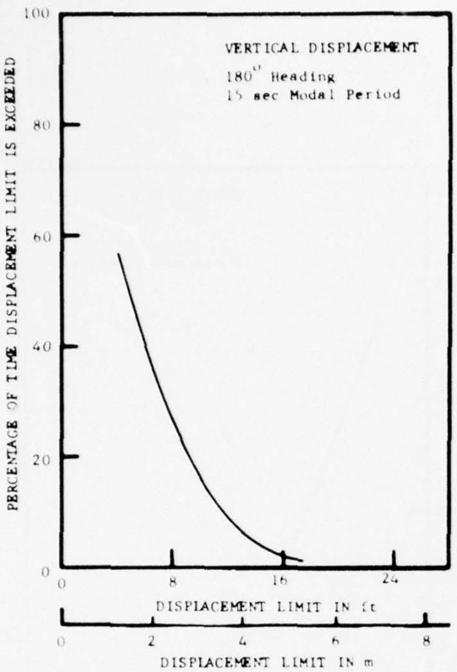


Figure 5e - Vertical Displacement at the Bow Gun in Long Crested Waves

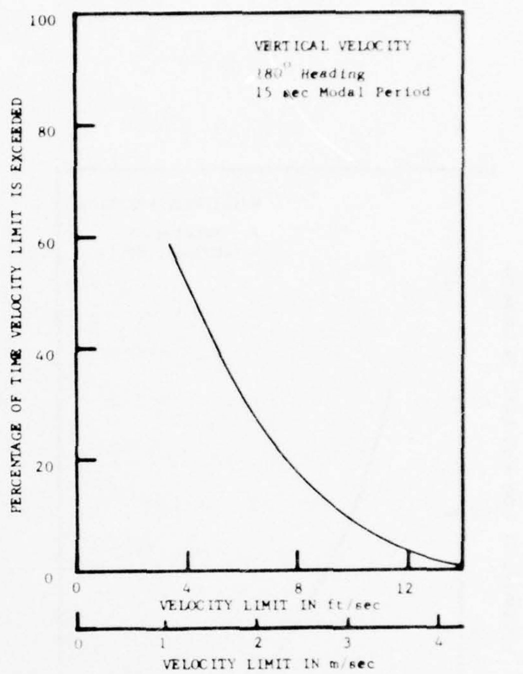


Figure 5f - Vertical Velocity at the Bow Gun in Long Crested Waves

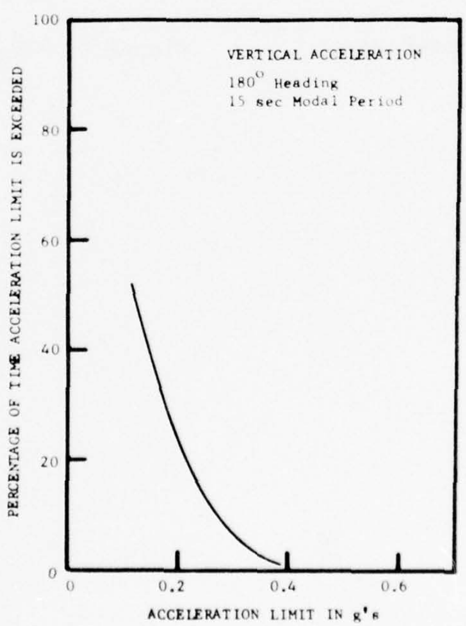


Figure 5g - Vertical Acceleration at the Bow Gun in Long Crested Waves

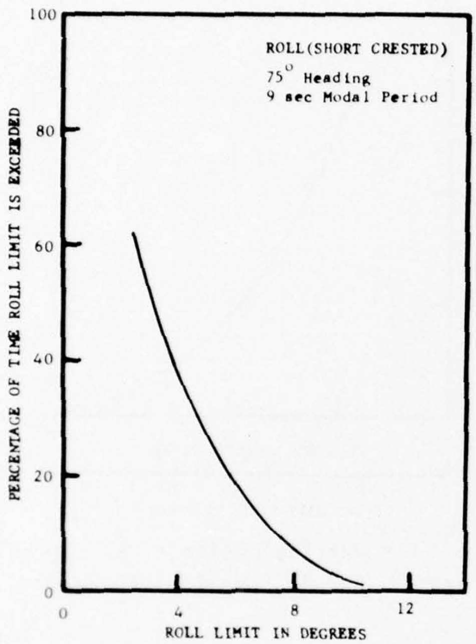


Figure 5h - Roll in Short Crested Waves

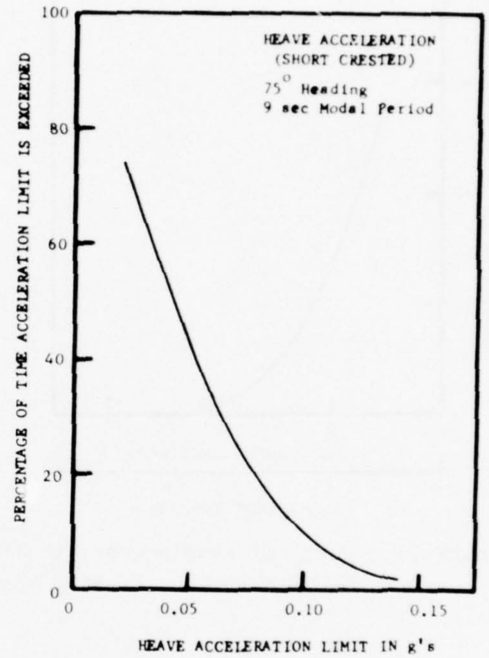


Figure 5i - Vertical Acceleration in Short Crested Waves

Figure 6 - Conditional Probability Density Functions for Time Duration Given the Response Limit is Exceeded for 30-Knot Speed in Sea State 6 (16.9 ft (5.15 m) Significant Wave Height)

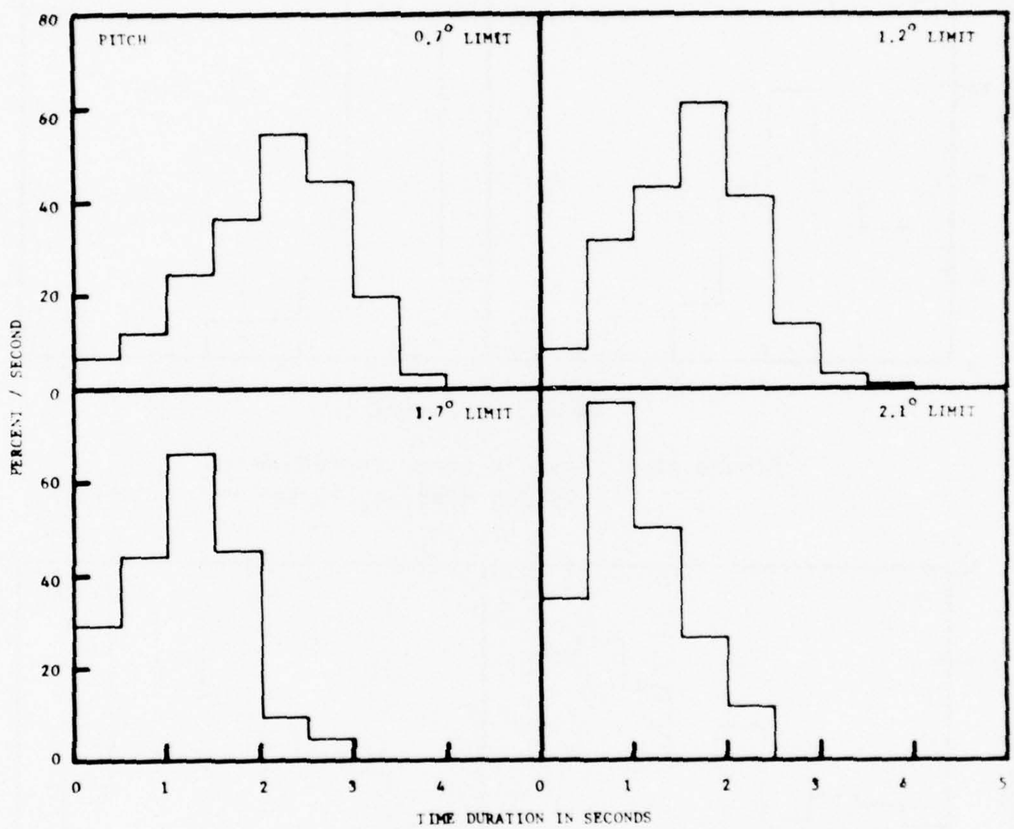


Figure 6a - Pitch in Long Crested Waves (180 deg Heading, 15 sec Modal Period)

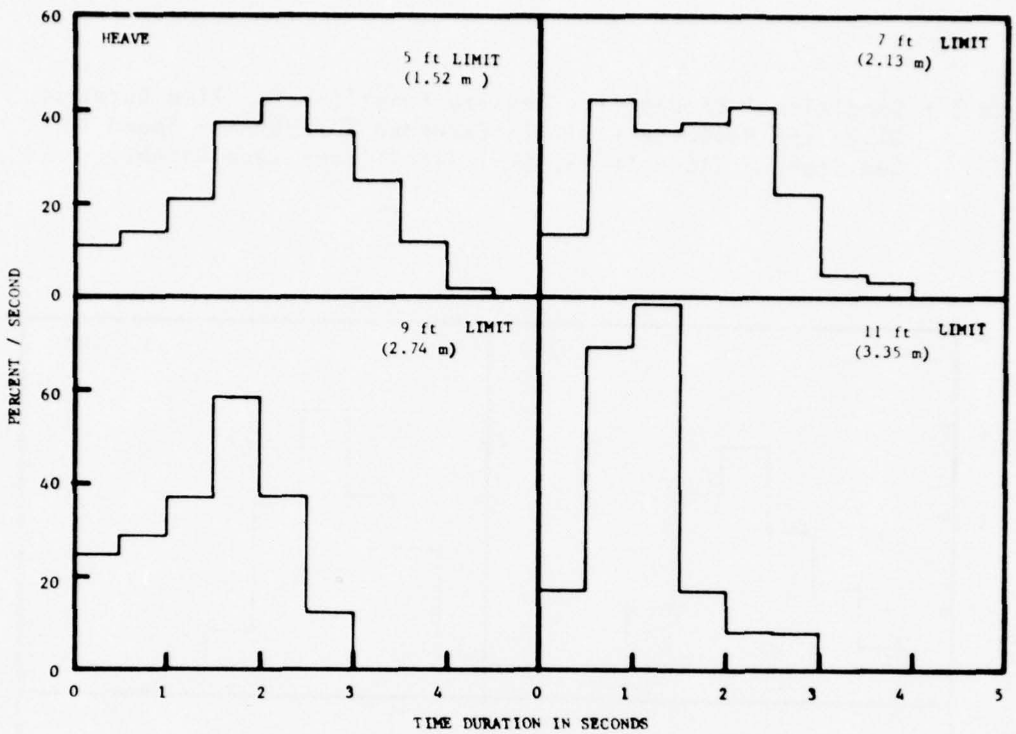


Figure 6b - Heave in Long Crested Waves
(105 deg Heading, 15 sec Modal Period)

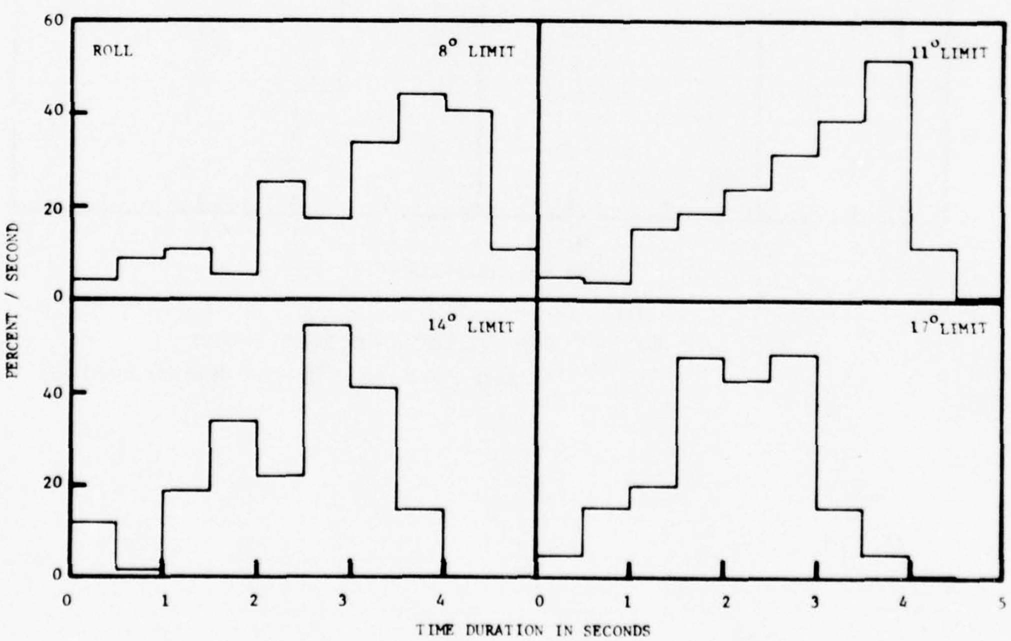


Figure 6c - Roll in Long Crested Waves
(75 deg Heading, 9 sec Modal Period)

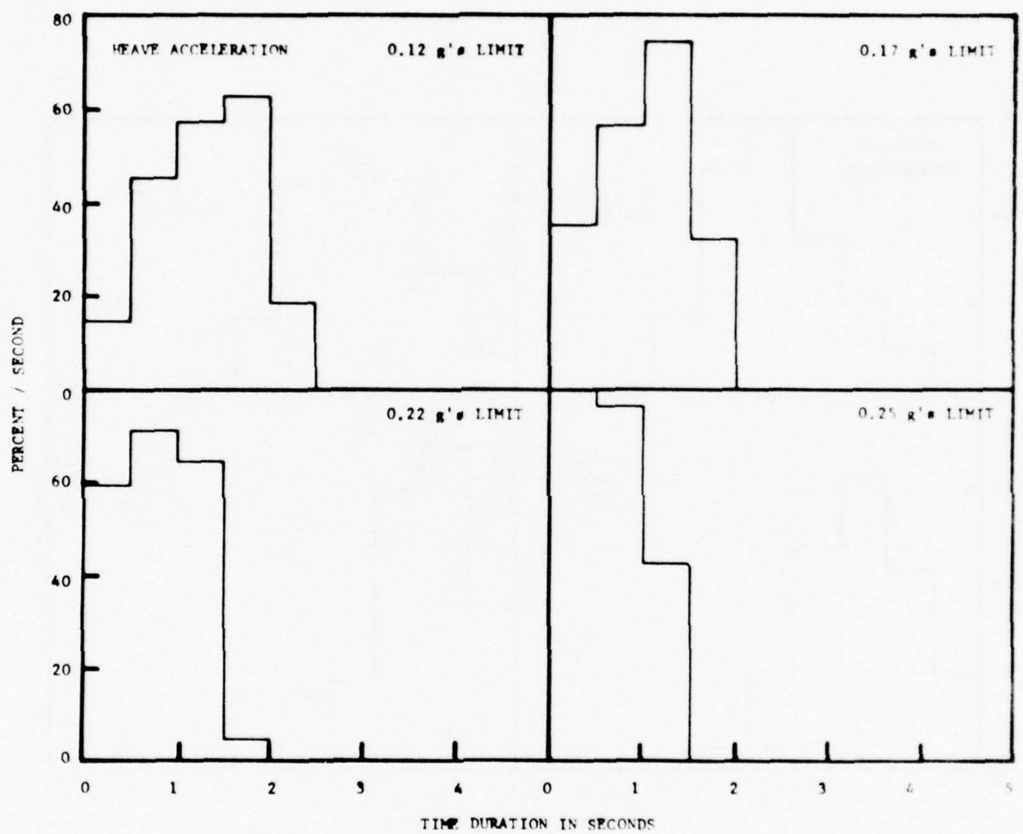


Figure 6d - Heave Acceleration in Long Crested Waves
(105 deg Heading, 9 sec Modal Period)

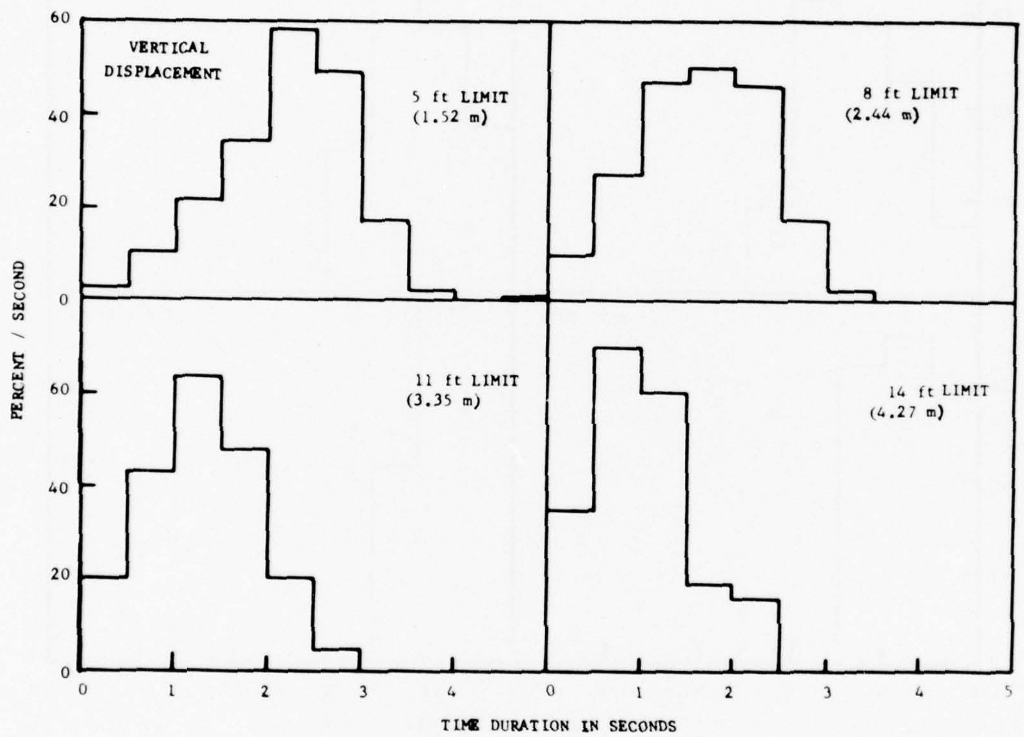


Figure 6e - Vertical Displacement at the Bow Gun in Long Crested Waves (180 deg Heading, 15 sec Modal Period)

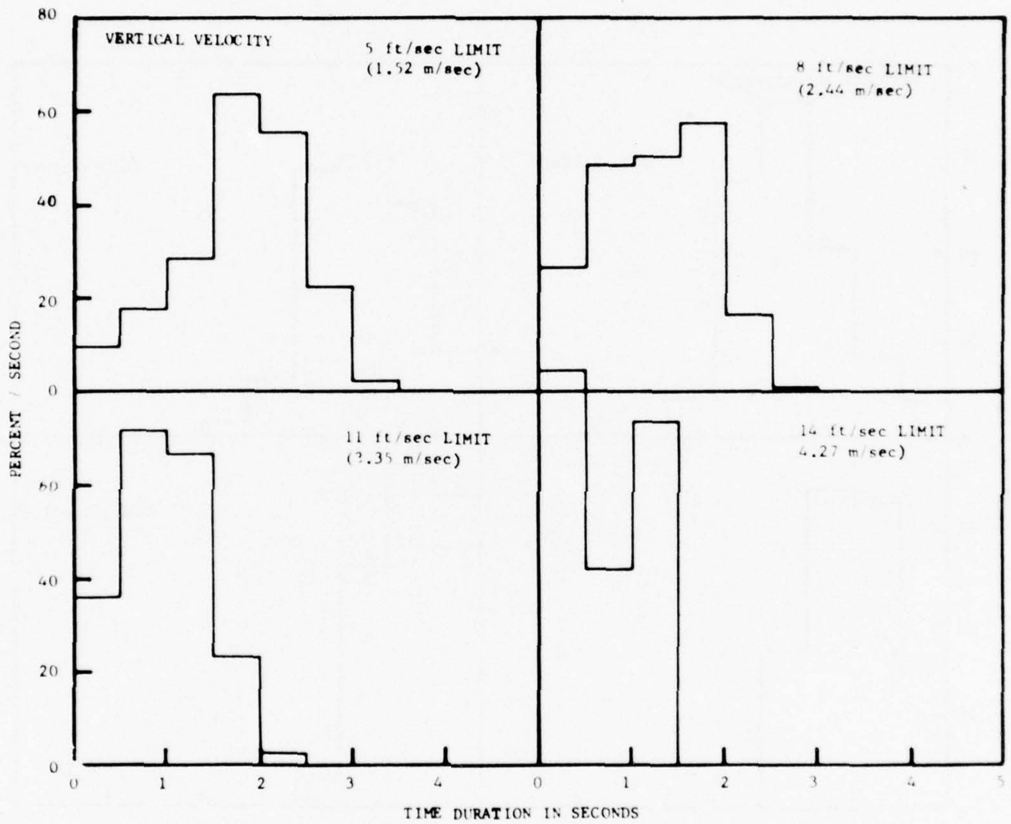


Figure 6f - Vertical Velocity at the Bow Gun in Long Crested Waves
(180 deg Heading, 15 sec Modal Period)

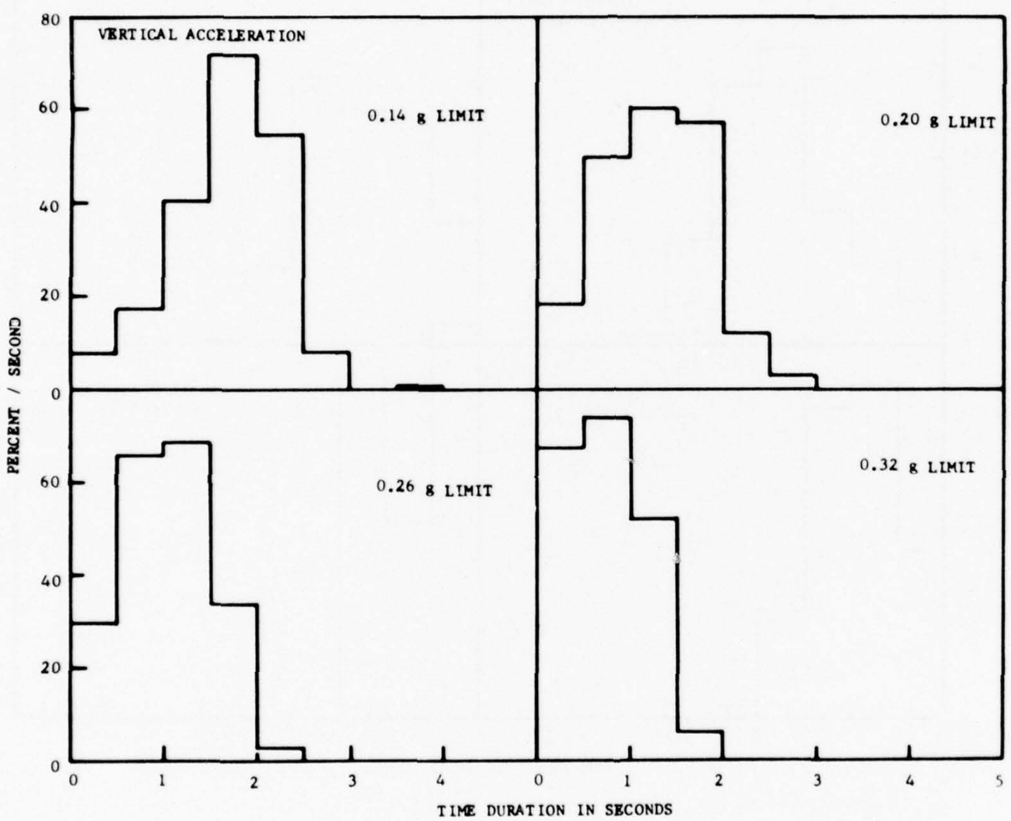


Figure 6g - Vertical Acceleration at the Bow Gun in Long Crested Waves (180 deg Heading, 15 sec Modal Period)

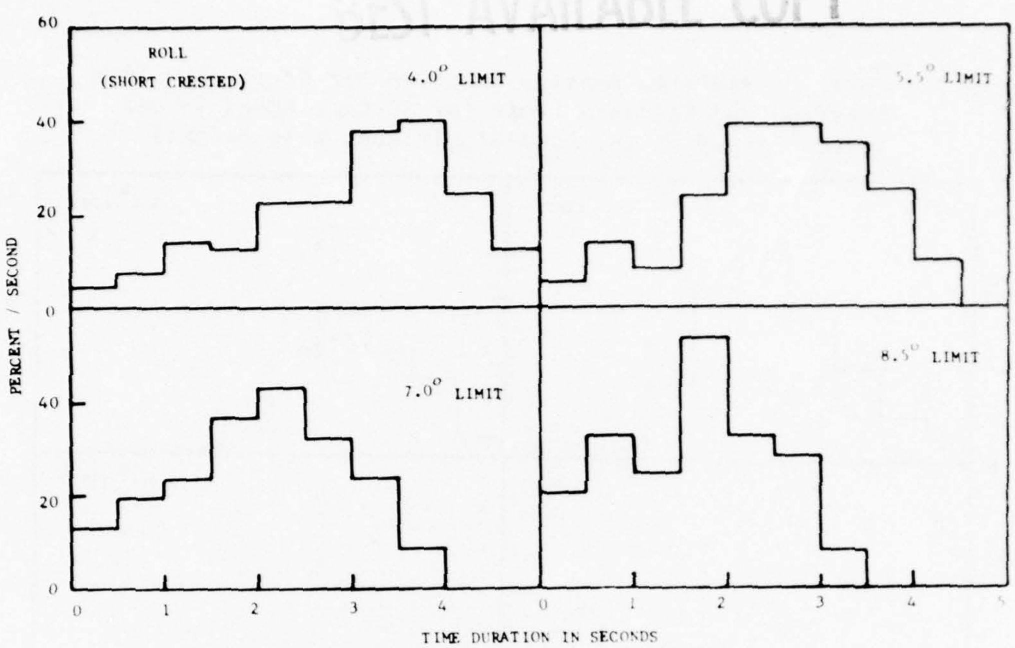


Figure 6h - Roll in Short Crested Waves
(75 deg Heading, 9 sec Modal Period)

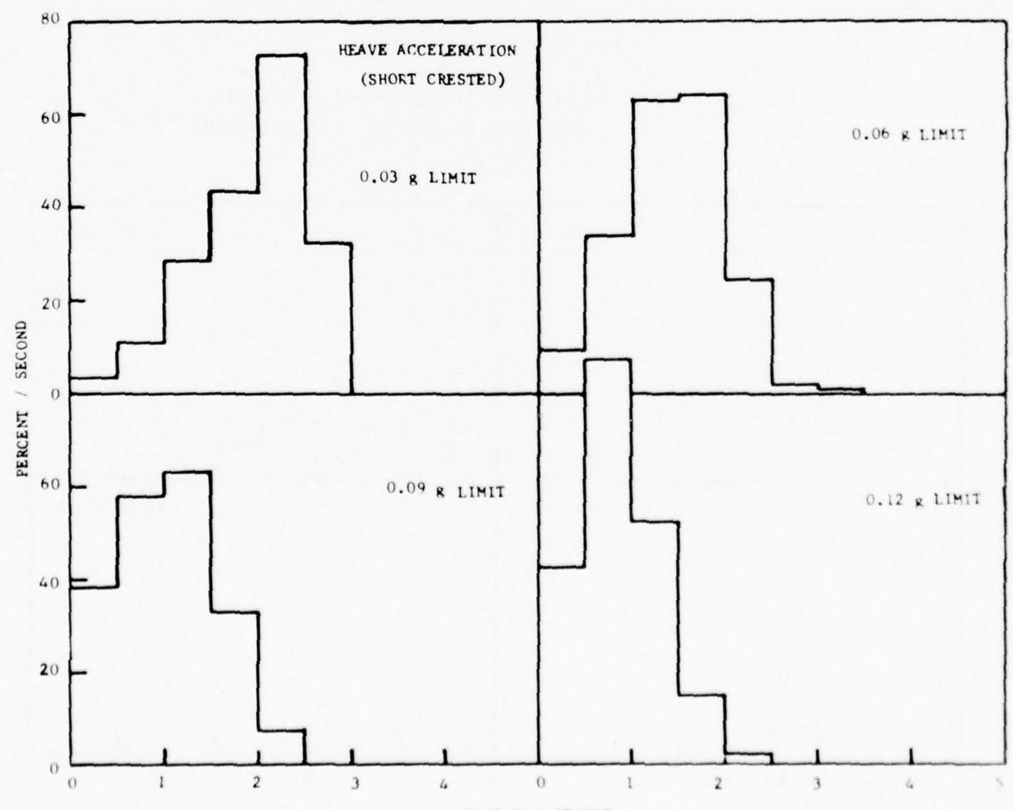


Figure 6i - Vertical Acceleration in Short Crested Waves
(75 deg Heading, 9 sec Modal Period)

Figure 7 - Joint Probability Density Function Bar Graphs for Time Duration and Response Limit for 30-Knot Speed in Sea State 6 (16.9 ft (5.15 m) Significant Wave Height)

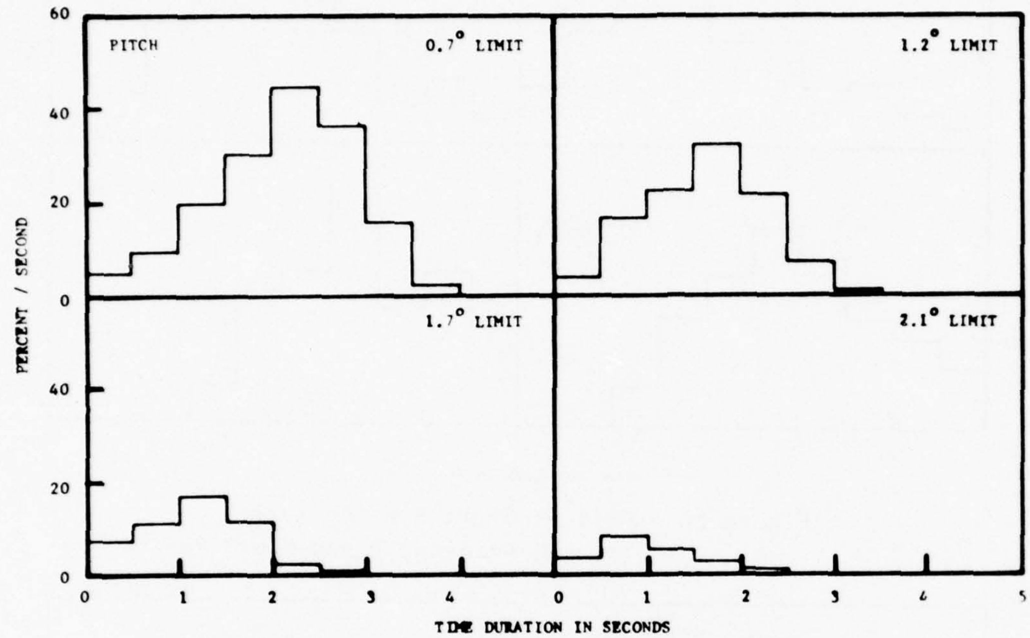


Figure 7a - Pitch in Long Crested Waves (180 deg Heading, 15 sec Modal Period)

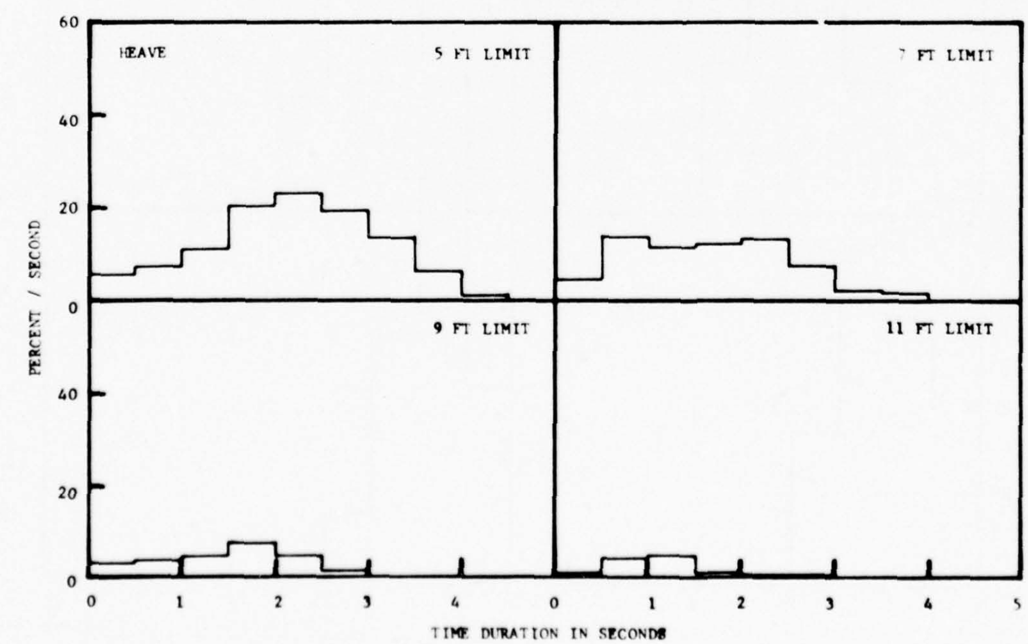


Figure 7b - Heave in Long Crested Waves (105 deg Heading, 15 sec Modal Period)

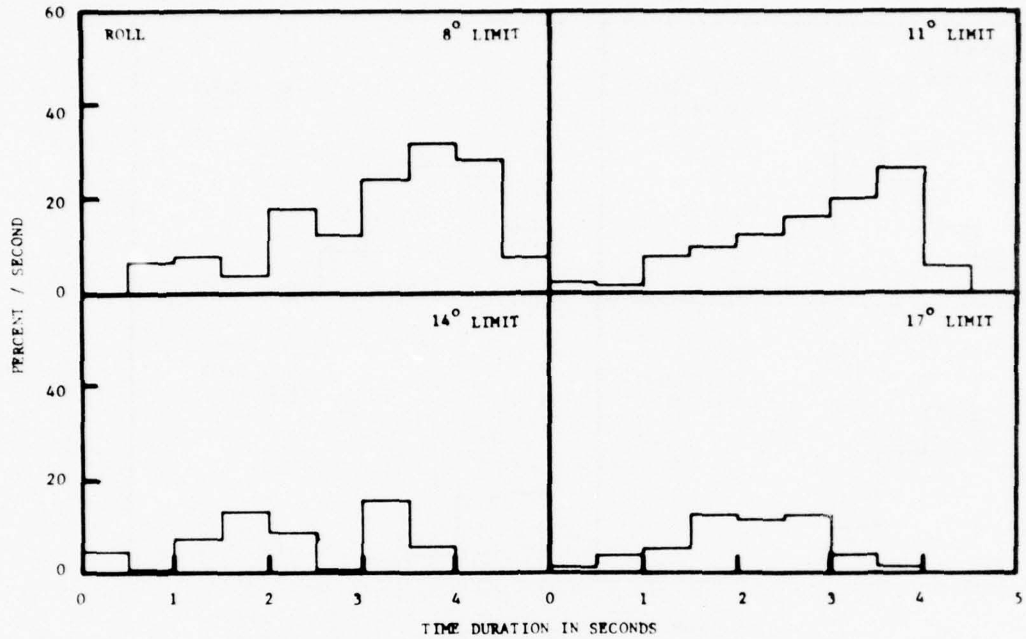


Figure 7c - Roll in Long Crested Waves
(75 deg Heading, 9 sec Modal Period)

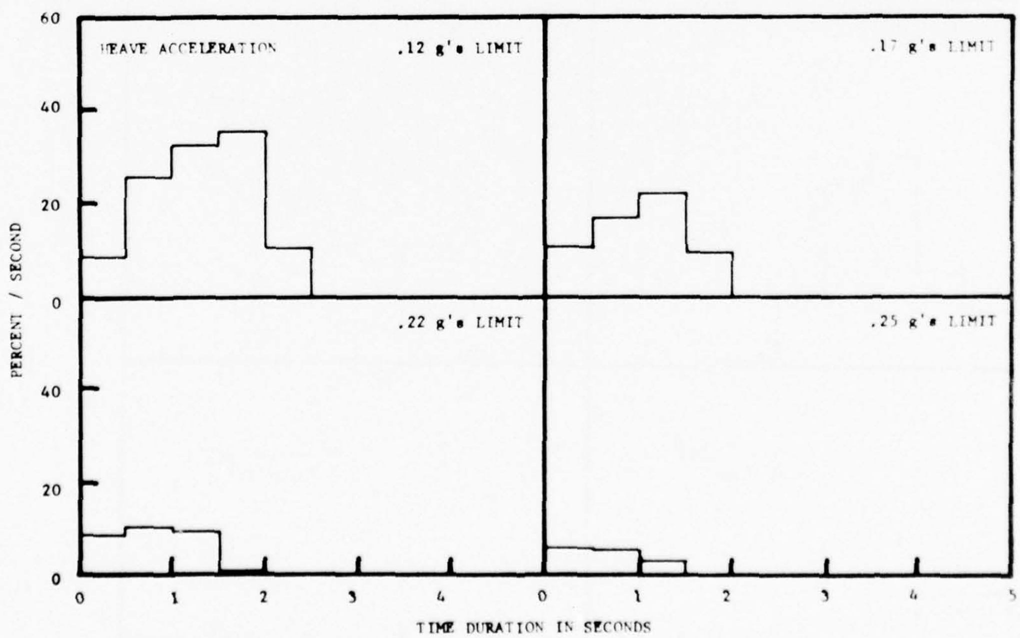


Figure 7d - Heave Acceleration in Long Crested Waves
(105 deg Heading, 9 sec Modal Period)

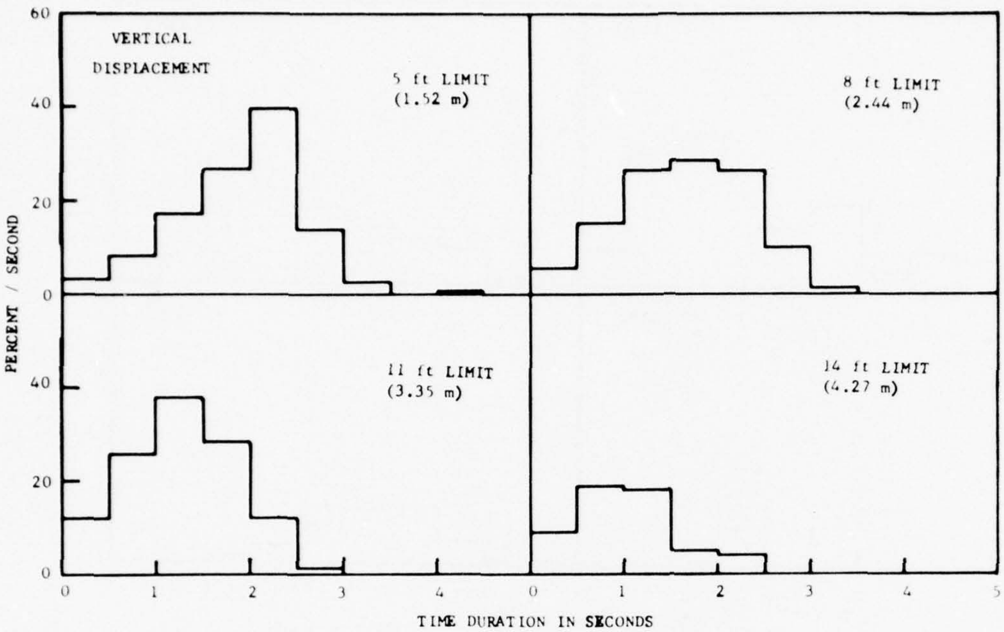


Figure 7e - Vertical Displacement at the Bow Gun in Long Crested Waves
(180 deg Heading, 15 sec Modal Period)

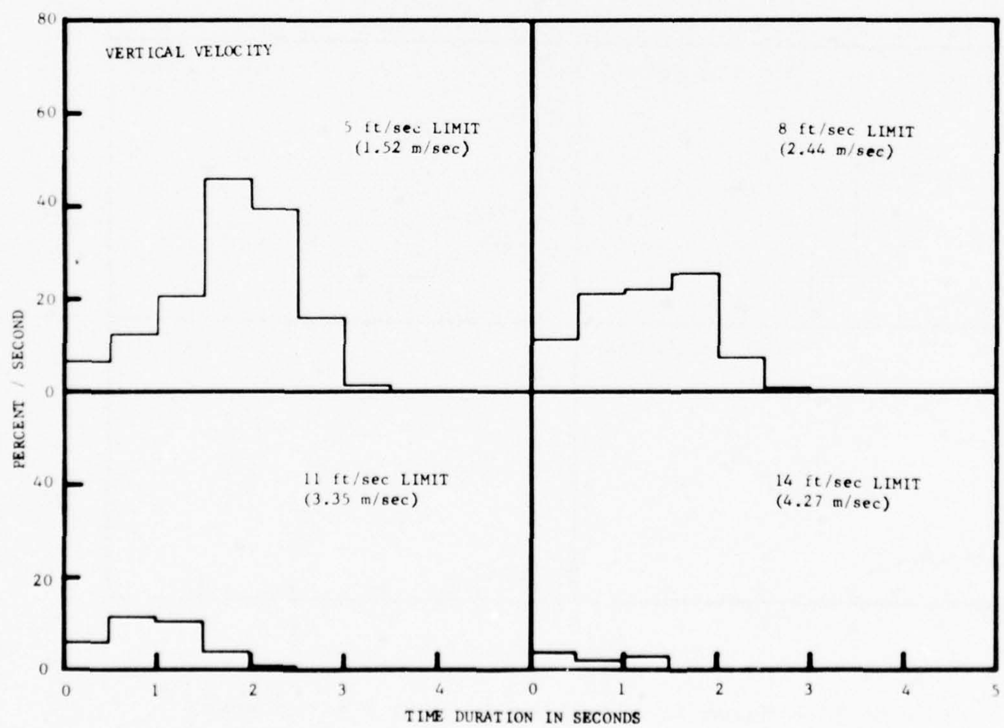


Figure 7f - Vertical Velocity at the Bow Gun in Long Crested Waves
(180 deg Heading, 15 sec Modal Period)

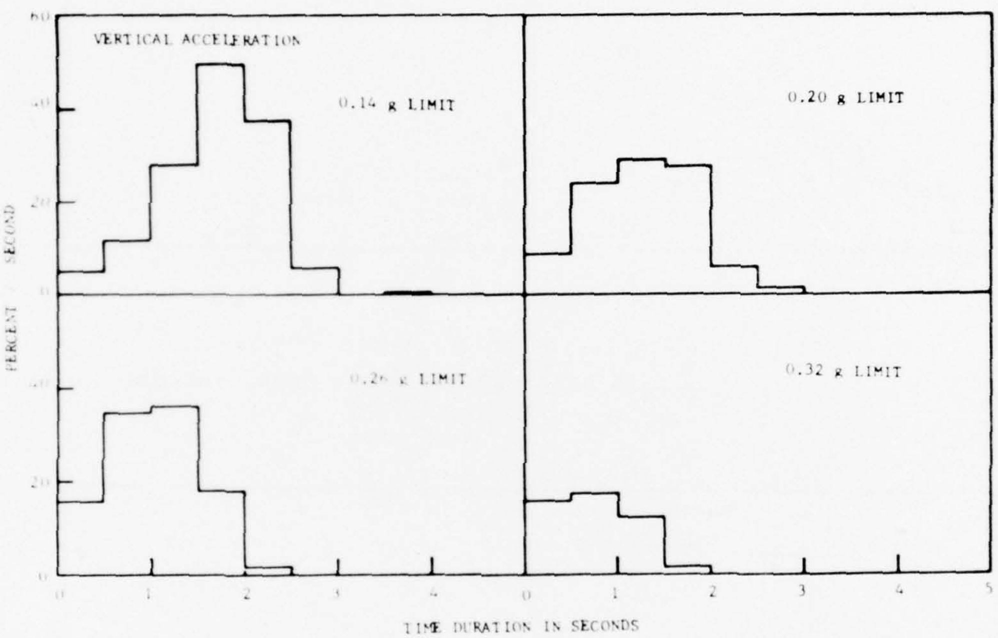


Figure 7g - Vertical Acceleration at the Bow Gun in Long Crested Waves (180 deg Heading, 15 sec Modal Period)

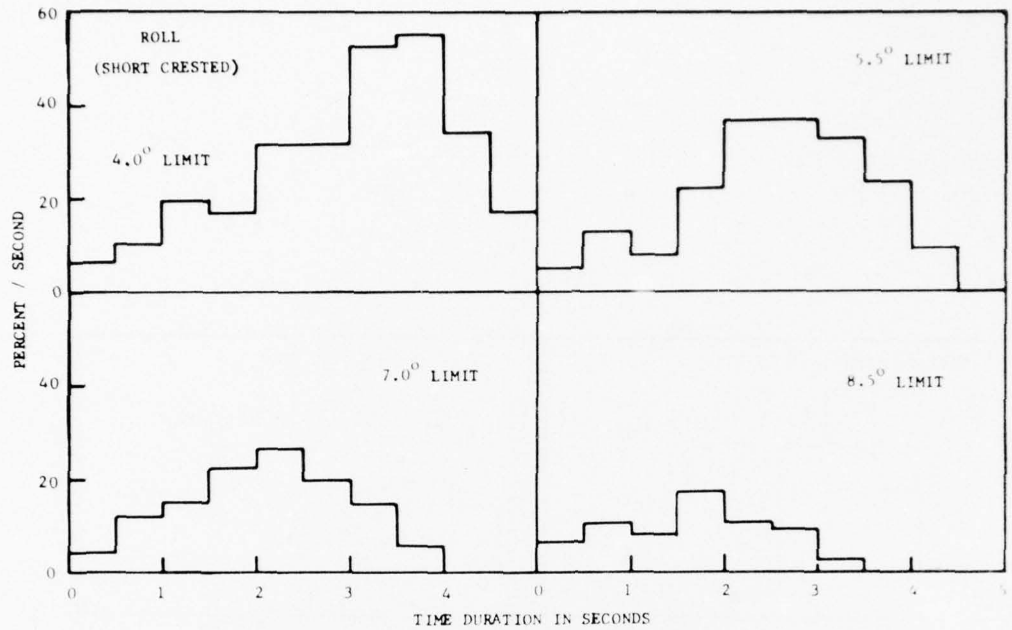


Figure 7h - Roll in Short Crested Waves
(75 deg Heading, 9 sec Modal Period)

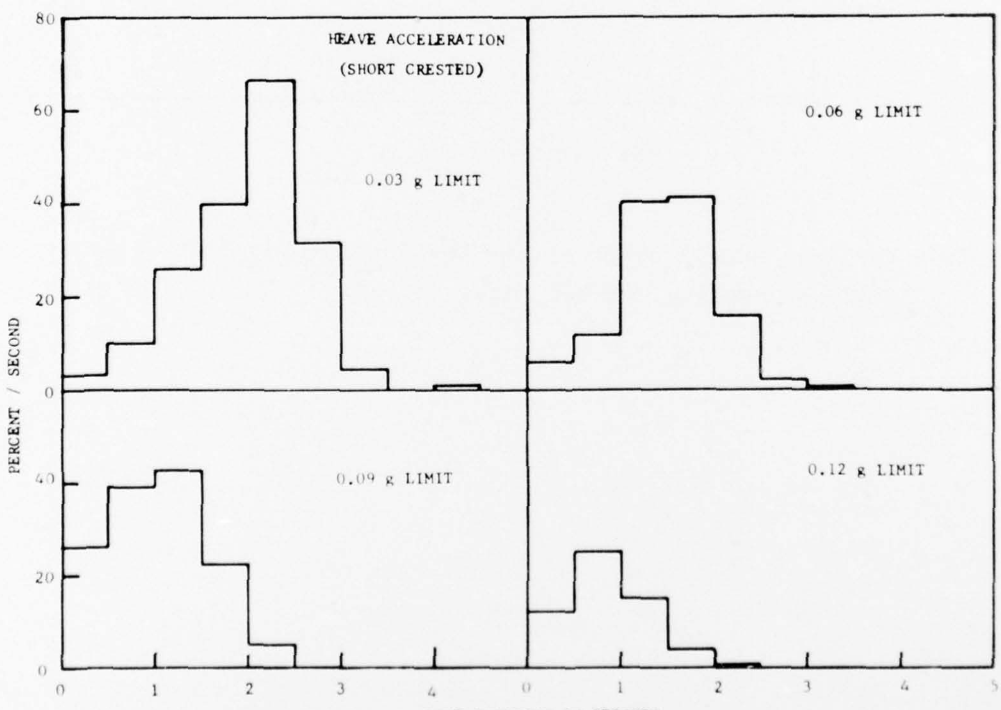


Figure 7i - Vertical Acceleration in Short Crested Waves
(75 deg Heading, 9 sec Modal Period)

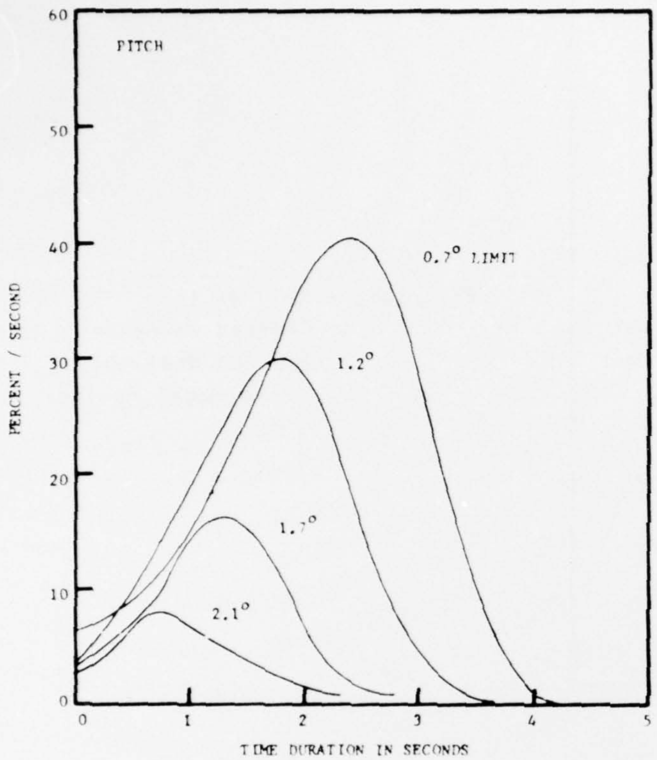


Figure 8 - Joint Probability Density Function Curves for Time Duration and Response Limit for 30-Knot Speed in Sea State 6 (16.9 ft (5.15 m) Significant Wave Height)

Figure 8a - Pitch in Long Crested Waves (180 deg Heading, 15 sec Modal Period)

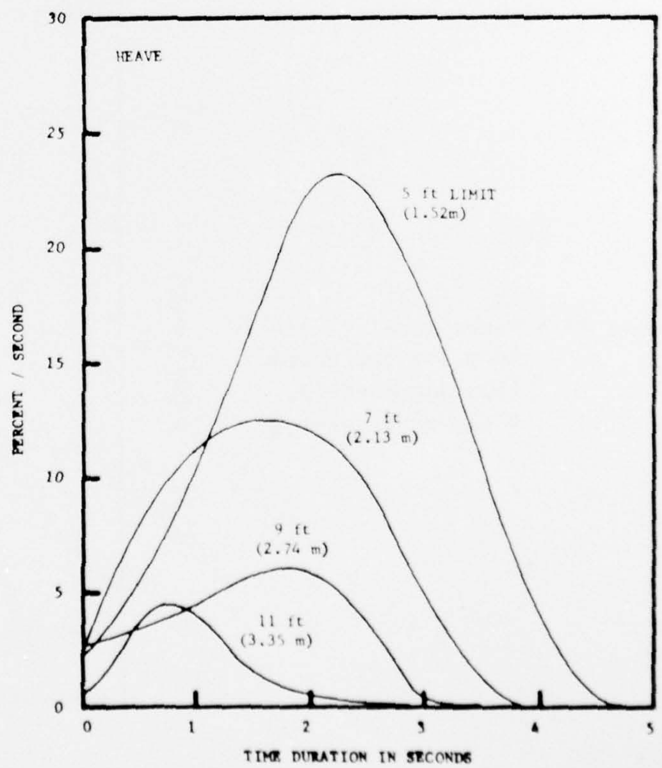


Figure 8b - Heave in Long Crested Waves (105 deg Heading, 15 sec Modal Period)

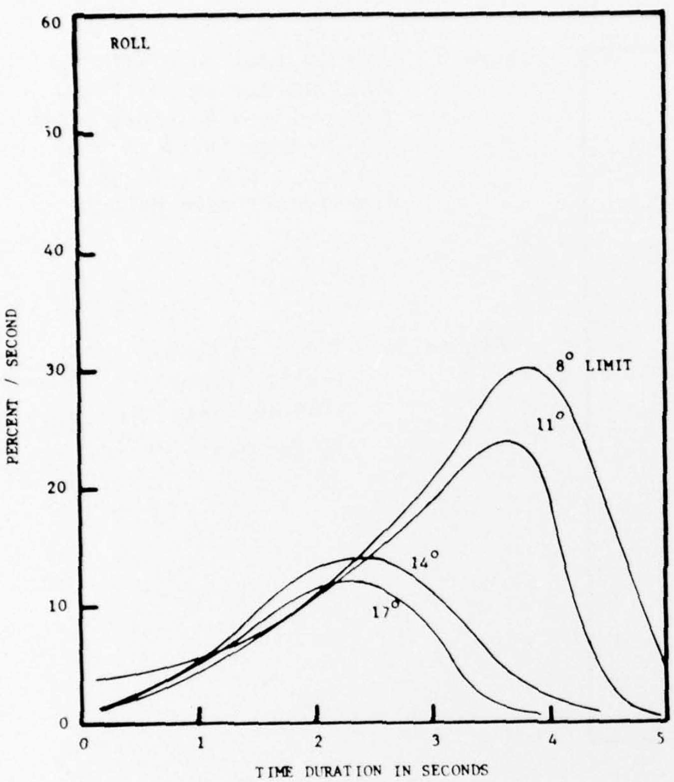


Figure 8c - Roll in Long Crested Waves (75 deg Heading, 9 sec Modal Period)

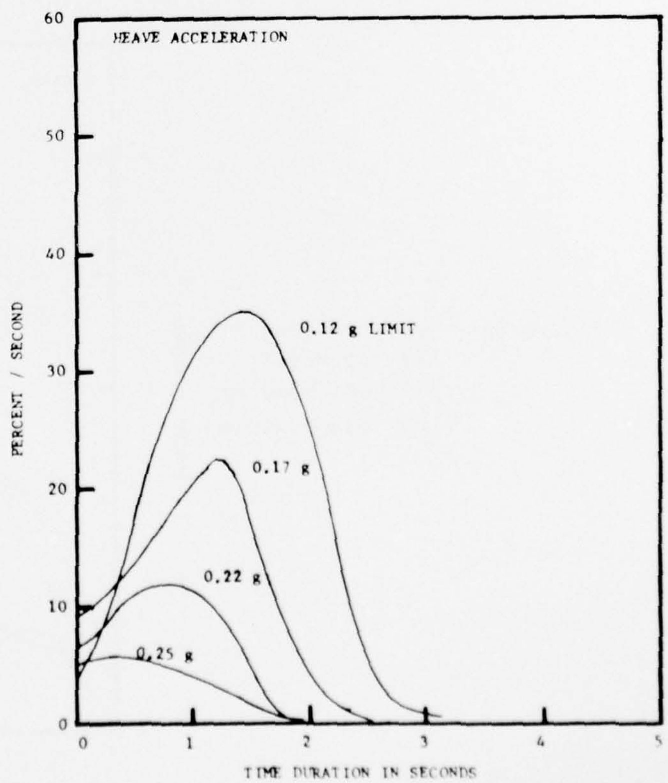


Figure 8d - Heave Acceleration in Long Crested Waves (105 deg Heading, 9 sec Modal Period)

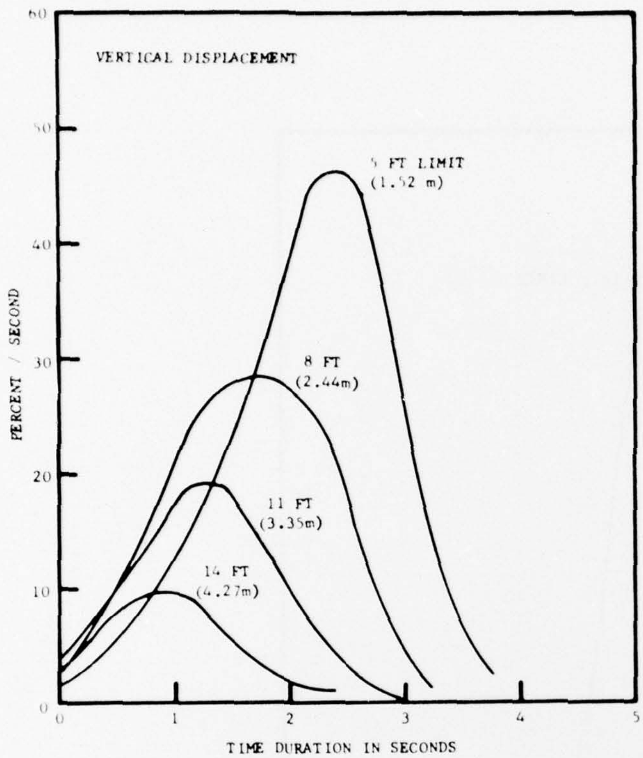


Figure 8e - Vertical Displacement at the Bow Gun in Long Crested Waves (180 deg Heading, 15 sec Modal Period)

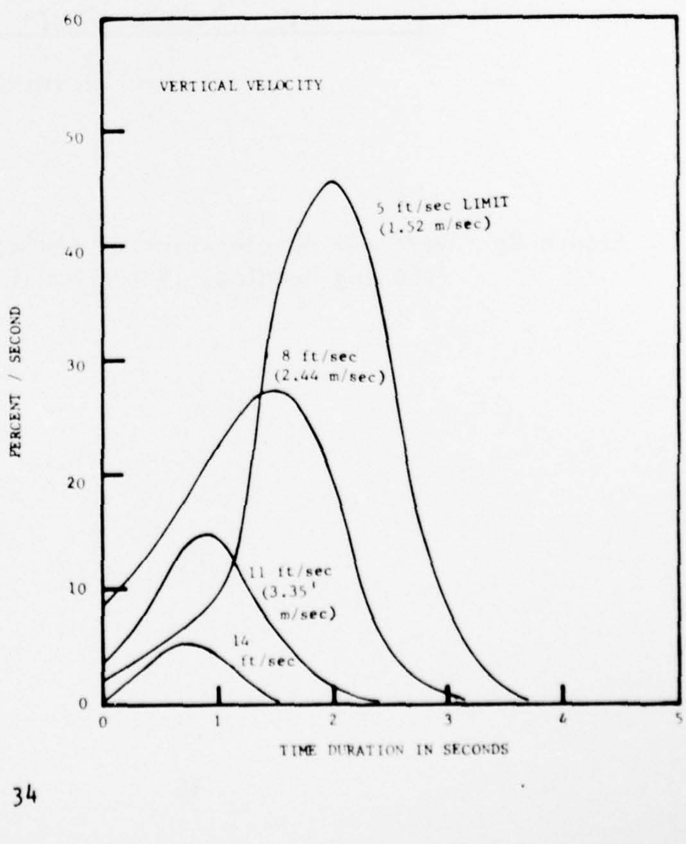


Figure 8f - Vertical Velocity at the Bow Gun in Long Crested Waves (180 deg Heading, 15 sec Modal Period)

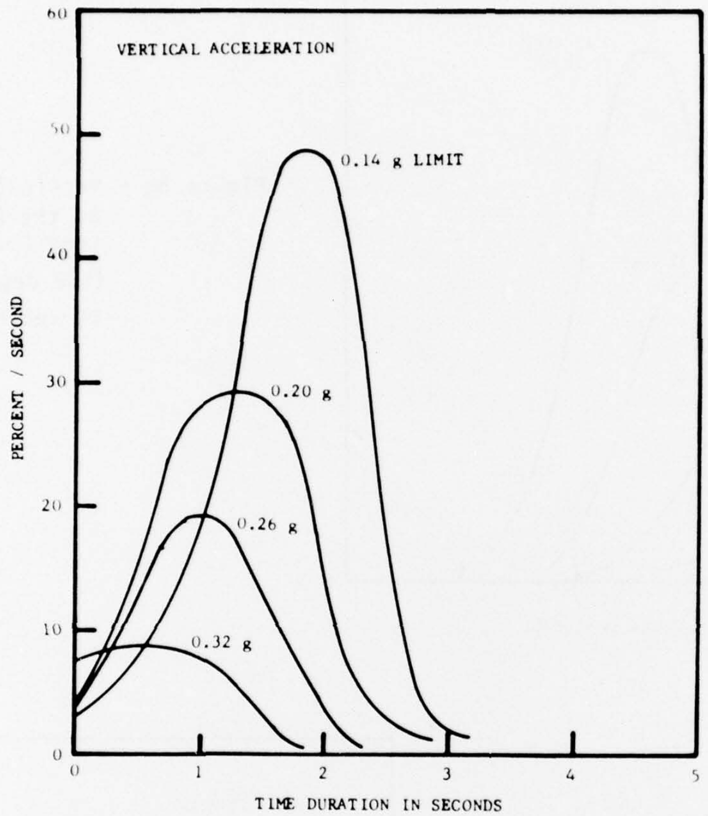


Figure 8g - Vertical Acceleration at the Bow Gun in Long Crested Waves (180 deg Heading, 15 sec Modal Period)

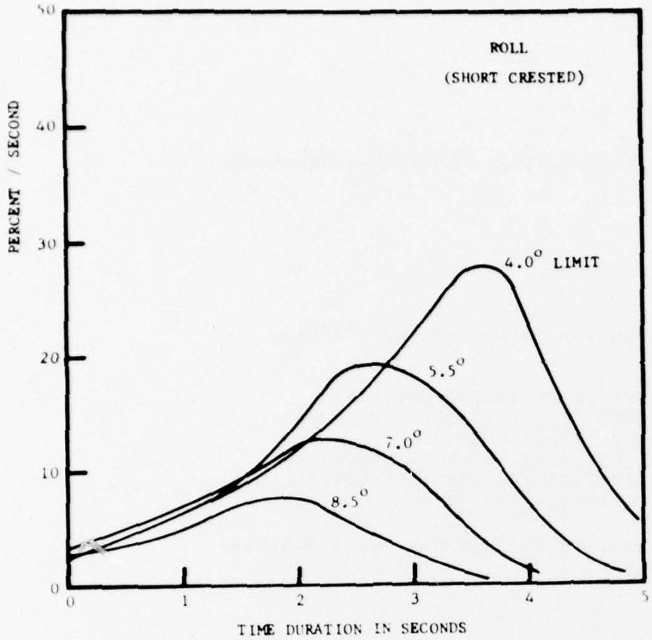


Figure 8h - Roll in Short Crested Waves (75 deg Heading, 9 sec Modal Period)

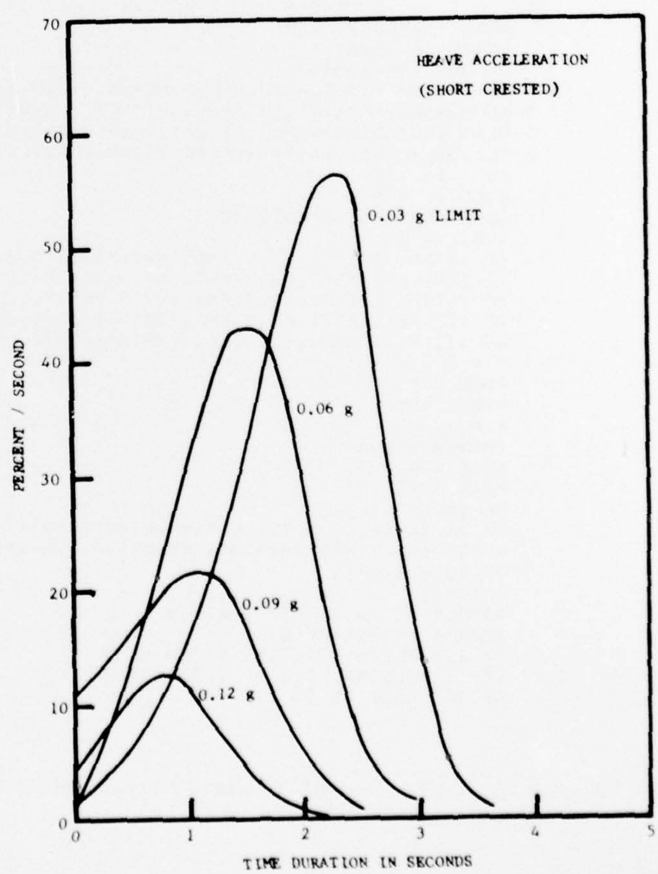


Figure 8i - Vertical Acceleration in Short Crested Waves (75 deg Heading, 9 sec Modal Period)

```
CHTAPRB,CM77777,T200,P2.
CHARGE,
FTN,A,T,OPT=1,R=3.
PAUSE.  JOB REQUIRES DISK PACK DV4752
MOUNT,VSN=DV4752,SN=CSGN02.
ATTACH,TAPE50,CSGNLCRTHROLLVACC17FT9SEC07530TP50,ID=CHTA,MR=1,SN=CSGN02.
LGO.
0000000000000000000000  END OF RECORD


C$     DEBUG
C$     ARRAYS
      PROGRAM LIMIT (INPUT,OUTPUT,TAPE5=INPUT,TAPE6=OUTPUT,TAPE50,
     2 DEBUG=OUTPUT)
      COMMON /ZC/ SAMPLE(3600),NCYCLS
      DIMENSION THIST(19,4,30),TIMES(21),ISIGN(3600),UNITS(6)
      DIMENSION FPROB(21),TPROB(20),NOCC(21),XTP(3600) , PROBJ(21)
      DIMENSION TITLE(8),SIGWH(4),TMODAL(4),CTITL(19)
      DIMENSION RESPTH(50,30),TITL(8),PNTITL(3,50),RSTITL(3,50),
     2 IPOINT(50),IMOTN(50),ITYPE(50),IPNT(50),XAP(50),YCL(50),ZBL(50),
     3 DBLWL(50),XSTAR(50),YSTAR(50),ZSTAR(50),XMU(50)
      REAL LIM,MEAN
      DATA TIMES /0.0,0.5,1.0,1.5,2.0,2.5,3.0,3.5,4.0,4.5,5.0,5.5,6.0,
     2 6.5,7.0,7.5,8.0,8.5,9.0,9.5,10.0/
      DATA UNITS /10HDEGREES    ,
     2            10HFEET       ,
     2            10HDEG/SEC    ,
     2            10HFT/SEC     ,
     2            10HDEG/SEC**2,
     2            10HG'S        /
      READ (5,1000) NRSP
      WRITE (6,2005)
      DO 500 IRE=1,NRSP
      READ (50) TITLE,HEAD,SPEED,NSPEC,SIGWH,TMODAL,PI,X2PI,RD,NW,DW,
     2 NCHN,NREC,KPTS,DT,SR,TRUN,NPTS,CTITL,WVSLOP,TPST,ELL
      READ (50) NRESP,TITL,SIGWHT,PERMOD,NPOINT,IPNT,PNTITL,XAP,YCL,
     2 ZBL,DBLWL,DAPO,XSTAR,YSTAR,ZSTAR,RSTITL,IMOTN,ITYPE,IPOINT,XMU
      DO 5 I=1,21
    5 NOCC(I) = 0
      READ (5,1050) IRESP,LIM
      IUNIT = 2
      IF (ITYPE(IRESP).EQ.1.AND.IMOTN(IRESP).GT.3) IUNIT=1
      IF (ITYPE(IRESP).EQ.2.AND.IMOTN(IRESP).GT.9) IUNIT=3
      IF (ITYPE(IRESP).EQ.2.AND.IMOTN(IRESP).LE.9) IUNIT=4
      IF (ITYPE(IRESP).EQ.3.AND.IMOTN(IRESP).GT.15) IUNIT=5
      IF (ITYPE(IRESP).EQ.3.AND.IMOTN(IRESP).LE.15) IUNIT=6
      M = 0
      IOCC = 0
      NTOCC = 0
      K = 0
      TMPROB = 0.0
      TIME = 0.0
      MEAN = 0.
      DO 100 NR=1,NREC
      IF (KPTS*NR.GT.NPTS) KPTS=MOD(NPTS,KPTS)
      READ (50) ((RESPTH(I,J),I=1,NRESP),J=1,KPTS)
      DO 50 N=1,KPTS
      K = K+1
      SAMPLE (K) = RESPTH(IRESP,N)
      MEAN = MEAN+SAMPLE(K)
      IF (SAMPLE(K).GE.0.0) ISIGN(K)=1
      IF (SAMPLE(K).LT.0.0) ISIGN(K)=2
      IF (K.EQ.1) GO TO 31
```

Figure A1 - Listing of Limit Program with Control Cards and Data

```
      IF (ABS(SAMPLE(K-1)).LE.LIM.AND.ABS(SAMPLE(K)).GT.LIM) GO TO 15
      IF (ABS(SAMPLE(K-1)).GT.LIM.AND.ABS(SAMPLE(K)).GT.LIM) GO TO 20
   10 IF (ABS(SAMPLE(K-1)).GT.LIM.AND.ABS(SAMPLE(K)).LE.LIM) GO TO 25
      GO TO 50
   15 TIME = 0.5
      IOCC = 1
      GO TO 50
   20 IF (ISIGN(K).NE.ISIGN(K-1)) GO TO 25
      TIME = TIME+0.5
      IOCC = IOCC+1
      GO TO 50
   25 IF (TIME.GT.10.0) GO TO 35
      DO 30 I=1,20
      IF (TIME.GT.TIMES(I).AND.TIME.LE.TIMES(I+1)) NOCC(I)=NOCC(I)+1
   30 CONTINUE
   31 IOCC = 0
      TIME = 0.0
      GO TO 50
   35 NOCC(21) = NOCC(21)+1
      M = M+1
      XTP(M) = (TIME/TRUN)*100.0
      IOCC = 0
      TIME = 0.0
   50 CONTINUE
  100 CONTINUE
      MEAN = MEAN/K
      CALL CYCLES (MEAN,K)
      DO 110 J=1,21
      NTOCC = NTOCC+NOCC(J)
  110 CONTINUE
      IF (NTOCC.EQ.0) GO TO 145
      DO 120 J=1,21
     PROBJ(J) = (FLOAT(NOCC(J))/FLOAT(NCYCLS))*100.0
      TMPROB = TMPROB + PROBJ(J)
  120 FPROB(J) = (FLOAT(NOCC(J))/FLOAT(NTOCC))*100.0
      DO 130 L=2,21
  130 TPROB(L-1) = (TIMES(L)*FLOAT(NOCC(L-1))/TRUN)*100.0
      DO 140 I=1,M
  140 ZTP = ZTP+XTP(I)
  145 WRITE (6,1500) TITLE,HEAD,SPEED,SIGWHT,PERMOD
      WRITE (6,1600) (RSTITL(J,IRESP),J=1,3),LIM,UNITS(IUNIT)
      IF (NPOINT.EQ.0) GO TO 148
      IPT = IPOINT(IRESP)
      IF (NSPEC.LT.0) WRITE (6,1540)
      IF (NSPEC.GT.0) WRITE (6,1530)
      WRITE (6,1650) (PNTITL(I,IPT),I=1,3)
      GO TO 149
  148 IF (NSPEC.LT.0) WRITE (6,1520)
      IF (NSPEC.GT.0) WRITE (6,1510)
  149 IF (NTOCC.EQ.0) GO TO 160
      WRITE (6,1700)
      DO 150 I=1,20
      WRITE (6,1800) TIMES(I),TIMES(I+1),NOCC(I),FPROB(I),TPROB(I)
     ,PROBJ(I)
  150 CONTINUE
      WRITE (6,1900) NOCC(21),FPROB(21),ZTP, PROBJ(21)
  160 IF (NTOCC.EQ.0) WRITE (6,2010)
      WRITE (6,2000) TRUN,SR,NCYCLS,TMPROB
      REWIND 50
  500 CONTINUE
 1000 FORMAT (I5)
 1050 FORMAT (I5,5X,F10.4)
 1500 FORMAT (*1*,//,21X,8A10,//,35X,*HEADING = *,F5.1,* DEGREES*,5X,
    2 *SPEED     = *,F4.1,* KNOTS*,/,35X,*SIG. WH = *,F5.2,* FEET*,8X,
    3 *MOD. PER. = *,F4.1,* SECONDS*)
 1510 FORMAT (*0*,//40X,*-- LONGCRESTED TIME HISTORY STATISTICS --*,
    2 /60X,*AT*,/56X,*THE ORIGIN*)
```

```
1520  FORMAT (*0*,//40X,*-- SHORTCRESTED TIME HISTORY STATISTICS --*,
    2 /61X,*AT*,/57X,*THE ORIGIN*)
1530  FORMAT (*0*,//40X,*-- LONGCRESTED TIME HISTORY STATISTICS --*,
    2 /60X,*AT*)
1540  FORMAT (*0*,//40X,*-- SHORTCRESTED TIME HISTORY STATISTICS --*,
    2 /61X,*AT*)
1600  FORMAT (*0*,34X,*RESPONSE =*3A10,/35X,*LIMIT     =*F6.2,1X,A10)
1650  FORMAT (* *,42X,3A10)
1700 FORMAT(*0*,44X,*NUMBER*,5X,*COND. PROB. OF*,4X,*TOTAL TIME*,7X,
    . *JOINT*/23X,*TIME DURATION*,11X,*OF*,7X,*DURATION TIME*,6X,
    .*EXCEEDED*,5X,*PROBABILITY*/  25X,*(SECONDS)*,11X,*EVENTS*,7X,
    . *(PERCENT)*,8X,*(PERCENT)*,5X,*(PERCENT)*/)
1800  FORMAT (* *,23X,F4.1,* - *,F4.1,11X,I3,10X,F6.2,10X,F6.2,8X,F6.2)
1900  FORMAT (* *,25X,* > 10.0*,13X,I3,10X,F6.2,10X,F6.2,8X,F6.2)
2000  FORMAT (*0*,19X,*NOTE:  TOTAL RUN TIME IS *,F6.1,
    2 * SECONDS AT A SAMPLE RATE OF *,F3.1,* POINTS PER SECOND.*,/,27X,
    3 *TOTAL NUMBER OF CYCLES IS*,I5,*.*,/,27X,*THE LIMIT IS EXCEEDED *
    4 *BY *,F6.2,* PERCENT OF THE CYCLES.*)
2005  FORMAT (*1*,5X,*DEFINITIONS:  NUMBER OF EVENTS = THE NUMBER OF *
    2 *TIMES THE LIMIT AMPLITUDE IS EXCEEDED FOR THE SPECIFIED TIME*
    3 * DURATION.*     //20X,*CONDITIONAL PROBABILITY OF DURATION TIME =
    4 THE PROBABILITY THAT THE SPECIFIED DURATION TIME WILL OCCUR, *
    5 /63X,*GIVEN THAT THE LIMIT AMPLITUDE HAS BEEN EXCEEDED.*//20X,
    6 *TOTAL TIME EXCEEDED = THE PERCENT OF THE TOTAL RUN TIME THAT THE
    7 LIMIT AMPLITUDE IS EXCEEDED*/41X* FOR THE SPECIFIED DURATION*
    8 * TIME.*//20X,*JOINT PROBABILITY = THE PROBABILITY THAT, FOR ANY*
    9 * CYCLE, THE LIMIT AMPLITUDE WILL BE EXCEEDED AND*/40X,*THE*
    9 * DURATION TIME WILL BE AS SPECIFIED.*)
2010  FORMAT (*0*////,55X,11H** SORRY **,//,40X,*NO CYCLES WERE FOUND *
    2 *TO EXCEED THE LIMIT*//////////)
      STOP
      END
      SUBROUTINE CYCLES (MEAN,NP)
      REAL MEAN
      COMMON /ZC/ SAMPLE(3600),NCYCLS
      DATA EPS /1.E-10/
      NCYCLS = 0
      DO 50 IP=1,NP
      IF (IP.GT.1) GO TO 10
      PEAK = SAMPLE(1)
      TROUGH = PEAK
      SGNPRE = SIGN(1.,SAMPLE(1)-MEAN)
   10 CURR = SAMPLE(IP)-MEAN
      IF (ABS(CURR).LT.EPS) GO TO 50
      SGNCUR = SIGN(1.,CURR)
      IF (SGNCUR.NE.SGNPRE) GO TO 30
      IF (CURR.LT.0.) GO TO 20
      IF (SAMPLE(IP).LT.PEAK) GO TO 50
      PEAK = SAMPLE(IP)
      GO TO 50
   20 IF (SAMPLE(IP).GT.TROUGH) GO TO 50
      TROUGH = SAMPLE(IP)
      GO TO 50
   30 SGNPRE = SGNCUR
      NCYCLS = NCYCLS+1
   50 CONTINUE
      RETURN
      END
0000000000000000000000  END OF RECORD


    1
    1      11.0
0000000000000000000000   END OF FILE
```

TABLE 1 - COMPUTER-PREDICTED PARTICULARS FOR CONVENTIONAL HULL C 17.2

Displacement, S.W., long tons (Tonnes)	16,866 (17,136)
Length between Perpendiculars, ft (m)	666.0 (203.0)
Beam, ft (m)	76.46 (23.31)
LCG, aft of Midship, ft (m)	8.47 (2.58)
Transom Width, ft (m)	41.40 (12.62)
Waterplane Area, ft (m)	37,279 (3463)
Vertical Center of Gravity, KG, ft (m)	28.00 (8.53)
Transverse Metacenter, GM, ft (m)	7.38 (2.25)
Vertical Center of Buoyancy, KB, ft (m)	13.01 (3.97)
Vertical Metacentric Height, KM, ft (m)	35.38 (10.78)
Block Coefficient, C_b	0.52
Midship Section Coefficient, C_x	0.89
Prismatic Coefficient, C_p	0.59

TABLE 2 - CALCULATION CONDITIONS (SPEEDS, HEADINGS AND SEA CONDITIONS)

Ship Speeds, knots			5			20			30				
Headings, deg	0	15	30	45	60	75	90	105	120	135	150	165	180
Wave Spectra Modal Perod, sec			9		11		13		15				

NOTES: (A) All wave spectra have a 1.0-ft (0.3048 m) significant wave height (double amplitude).

(B) Motion, velocity and acceleration rms responses can be obtained for any sea state by multiplying the predicted rms values by the significant wave height of the sea.

(C) 180-deg heading is head seas.

TABLE 3 - RESPONSE AMPLITUDE LIMITS AND NUMBER OF CYCLES WHICH EXCEED THE LIMIT

Ship Response	Heading* (deg)	Sea Spectra Modal Period (sec)	Response rms	First Limit/ Number of Events	Second Limit/ Number of Events	Third Limit/ Number of Events	Fourth Limit/ Number of Events
Long-crested							
Pitch, deg	180	15	2.1	0.7/393	1.2/252	1.7/123	2.1/52
Heave, ft	105	15	9.1	5.0/202	7.0/118	9.0/48	11.0/23
m			2.77	1.52/202	2.13/118	2.74/48	3.35/23
Roll, deg	75	9	20.3	8.0/217	11.0/159	14.0/117	17.0/79
Vertical Acceleration, g's	105	9	0.22	0.12/337	0.17/179	0.22/84	0.25/42
Long-crested At Bow Gun							
Vertical Displacement, ft	180	15	7.12	5.0/367	8.0/264	11.0/138	14.0/63
m			2.17	1.52/367	2.44/264	3.35/138	4.27/63
Velocity, ft/sec	180	15	5.79	5.0/357	8.0/219	11.0/78	14.0/19
m/sec			1.76	1.52/357	2.44/219	3.35/78	4.27/19
Acceleration, g's	180	15	0.16	0.14/374	0.20/263	0.26/143	0.34/65
Short-crested At Ship CG							
Roll	75	9	4.4	4.0/210	5.5/143	7.0/93	8.5/19
Vertical Acceleration	75	9	0.06	0.03/510	0.06/359	0.09/187	0.12/80

*180-deg heading is head seas.

TABLE A.1 - SAMPLE OUTPUT FOR PROGRAM LIMIT

HEADING = 75.0 DEGREES SPEED = 30.0 KNOTS
SIG. WH = 16.90 FEET MOD. PER. = 9.0 SECONDS

POINT = ORIGIN

LIMIT = ROLL > 11.00 DEGREES

TIME DURATION (SECONDS)	NUMBER OF EVENTS	COND. PROB. OF DURATION TIME (PERCENT)	TOTAL TIME EXCEEDED (PERCENT)	JOINT PROBABILITY (PERCENT)
0.0 - .5	4	2.52	.11	1.31
.5 - 1.0	3	1.89	.17	.98
1.0 - 1.5	12	7.55	1.00	3.93
1.5 - 2.0	15	9.43	1.67	4.92
2.0 - 2.5	19	11.95	2.64	6.23
2.5 - 3.0	25	15.72	4.17	8.20
3.0 - 3.5	31	19.50	6.03	10.16
3.5 - 4.0	41	25.79	9.11	13.44
4.0 - 4.5	9	5.66	2.25	2.95
4.5 - 5.0	0	0.00	0.00	0.00
5.0 - 5.5	0	0.00	0.00	0.00
5.5 - 6.0	0	0.00	0.00	0.00
6.0 - 6.5	0	0.00	0.00	0.00
6.5 - 7.0	0	0.00	0.00	0.00
7.0 - 7.5	0	0.00	0.00	0.00
7.5 - 8.0	0	0.00	0.00	0.00
8.0 - 8.5	0	0.00	0.00	0.00
8.5 - 9.0	0	0.00	0.00	0.00
9.0 - 9.5	0	0.00	0.00	0.00
9.5 - 10.0	0	0.00	0.00	0.00
> 10.0	0	0.00	0.00	0.00

NOTE: TOTAL RUN TIME IS 1800.0 SECONDS AT A SAMPLE RATE OF 2.0 POINTS PER SECOND.
TOTAL NUMBER OF CYCLES IS 305.
THE LIMIT IS EXCEEDED BY 52.13 PERCENT OF THE CYCLES.

DTNSRDC ISSUES THREE TYPES OF REPORTS

(1) DTNSRDC REPORTS, A FORMAL SERIES PUBLISHING INFORMATION OF *PERMANENT TECHNICAL VALUE, DESIGNATED BY A SERIAL REPORT NUMBER.*

(2) DEPARTMENTAL REPORTS, A SEMIFORMAL SERIES, RECORDING INFORMATION OF A PRELIMINARY OR TEMPORARY NATURE, OR OF LIMITED INTEREST OR SIGNIFICANCE, CARRYING A DEPARTMENTAL ALPHANUMERIC IDENTIFICATION.

(3) TECHNICAL MEMORANDA, AN INFORMAL SERIES, USUALLY INTERNAL WORKING PAPERS OR DIRECT REPORTS TO SPONSORS, NUMBERED AS TM SERIES REPORTS; NOT FOR GENERAL DISTRIBUTION.